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(94) **High density two dimensional symbology.**

(97) A non-volatile electro-optical read-only memory includes a substrate on which is printed (or otherwise inscribed) a complex symbol or "label" with a high density two-dimensional symbology, a variable number of component symbols or "codewords" per row, and a variable number of rows. Codewords in alternating rows are selected from mutually exclusive subsets of a mark pattern such as a (17,4) mark pattern. The subsets are defined in terms of particular values or a discriminator function, which is illustrated as being a function of the widths of bars and spaces in a given codeword. In the illustrated embodiment, each subset includes 929 available codewords; that, plus a two-step method of decoding scanned data, permitting significant flexibility in defining mappings of human-readable symbol sets into codewords. The memory may be used in conjunction with a scanner and a suitable control system in a number of applications, e.g., robotic operations or automated microfilm searching.

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## NONVOLATILE ELECTRO-OPTICAL READ-ONLY MEMORY WITH HIGH DENSITY TWO DIMENSIONAL SYMBOLOGY

### 1. Background of the Invention

This present invention relates to a nonvolatile electro-optical read-only memory, comprising of a substrate on which is printed (or otherwise inscribed) a complex symbol or "label" with a high density two-dimensional symbology, a variable number of component symbols or "codewords" per line, and a variable number of lines.

#### 1.1 Bar Code Symbology

A bar code is typically a linear array of elements that are either printed directly on an object or on labels that are affixed to the object. As shown in Figures 1 and 2, bar code elements typically comprise bars and spaces, with bars varying widths representing strings of binary ones and spaces of varying widths representing strings of binary zeros. Many bar codes are optically detectable and are read by devices such as scanning laser beams or handheld wands. Other bar codes are implemented in magnetic media. The readers and scanning systems electro-optically decode the symbol to multiple alphanumerical characters that are intended to be descriptive of the article or some characteristic thereof. Such characters are typically represented in digital form as an input to a data processing system for applications in point-of-sale processing, inventory control, and the like. Scanning systems of this general type have been disclosed, for example, in U.S. Patent Nos. 4,251,798; 4,360,798; 4,369,361; 4,387,297; 4,409,470 and 4,480,120, all of which have been assigned to the same assignee as the instant application.

Most bar codes presently used contain only five or six letters or digits, no more than a typical vehicle license plate. In view of the relatively small amount of data contained in a typical linear bar code, the most typical applications of a bar code is to use the encoded data merely an index to a file or data base associated with the computer system comprehensive information is available.

As noted above, the contrasting parallel bars and spaces (referred to herein as "marks") of typical optically-detectable bar codes have varying widths. Generally, the bars and spaces can be no smaller than a specified minimum width, termed the code's "unit" (or "x dimension" or "module"). While the theoretical minimum unit size is the wavelength of the light being used to read the bar code, other practical limitations exist. Among these limitations are the desired depth of field of the reading equipment, the limitations of a given printing process, and the robustness of the printed image to be correctly read despite dust, dirt, and minor physical damage.

The bar code symbols are formed from bars or elements typically rectangular in shape with a variety of possible widths. The specific arrangement of elements defines the character represented according to a set of rules and definitions specified by the code or "symbology" used. The relative size of the bars and spaces is determined by the type of coding used, as is the actual size of the bars and spaces. The number of characters per inch represented by the bar symbol is referred to as the density of the symbol. To encode a desired sequence of characters, a collection of element arrangements are concatenated together to form the complete bar code symbol, with each character of the message being represented by its own corresponding group of elements. In some symbologies a unique "start" and "stop" character is used to indicate where the bar code begins and ends. A number of different bar code symbologies exist. These symbologies include UPS/EAN, Code 39, Code 93, Code 128, Codabar, and Interleaved 2 of 5.

#### 1.2 Symbologies of (n,k) Type

Some bar codes are referred to as belonging to the (n,k) family defined by Savir and Laurer in "The Characteristics and Decodeability of the Universal Product Code," IBM Systems Journal, Vol. 14, No. 1, 1975. A code of the (n,k) type represents characters uniquely by a string of n bits each containing k runs of one bit (i.e., k bars) and k runs of zero bits (i.e., spaces). An (n,k) code is decodable in both directions, i.e., by scanning it either forwards backwards. Such bar codes are often referred to by the numbers n and k; for example, the well-known Code 93 derives its name from this (n,k) notation, i.e., n = 9 and k = 3. The UPC code is an example of a (7,2) code, i.e., n = 7 and k = 2.

#### 1.3 Prior Two-Dimensional Bar Codes

Known two-dimensional bar codes exist that are extensions of one-dimensional bar codes, in that one-dimensional bar codes are stacked with horizontal guard bars between them to increase the density. An example of such bar codes is seen in U.S. Patent No. 4,794,239, to Allais.

An obstacle to increasing the density of two-dimensional bar codes is the need for a certain minimum height in the vertical direction. A minimum height is needed to ensure that a human operator can keep a "scan line: (i.e., the path of a given scanning motion, such as that achieved by passing a hand-held wand across a bar code) within the area of a single bar-code row. Figure 1 illustrates this difficulty: scan lines 10, 11, and 12 represent identical exemplar paths of, e.g., hand-held wands over the bar codes 15, 16, and 17. It will be seen that with a tall bar code 15, the scan lines 10 all stay within the confines of one bar code row, whereas with shorter bar codes 16 or 17, the scan lines 11 and 12 cross from one row to another.

Another limitation seen in some known two-dimensional bar codes is the use of fixed maps to translate from codewords to characters. The fixed maps restrict the flexibility of applications. For example, the well-known Code 49 has six fixed maps (i.e., six modes) to translate a codeword numerically or alphanumerically.

Although such two dimensional bar codes provide some increase in the storage capacity, such codes are still used as indices for file look-up, rather than as a complete data file in itself.

Still another drawback of some known two-dimensional codes is the need for a fixed number of codewords per line (referred to here as a "row") and the limitation of a maximum number of rows. For instance, Code 49 (a bar code generally in accordance with the aforementioned Allais '239 patent) has 4 codewords per row and 8 rows maximum.

Yet another problem is the lack of flexibility in choosing a suitable security system. (The term "security" is commonly used to refer to confidence in accuracy or correctness; it is usually specified by a misdecode rate, e.g., in errors per million.) Code 49, for example, provides a very high level of security while sacrificing about 30% of its codewords on average for checking errors. In some applications, however, a lesser degree of security may be an acceptable trade-off in return for a greater codeword density; the ability to vary the security would be advantageous.

## 2. Summary of the Invention

The present invention provides an improved high-density two-dimensional symbology, as well as a flexible method for using the symbology to encode and decode data. The symbology may be used to create a nonvolatile read-only memory, which in turn may be used in a computer system.

Prior codes have been restricted in terms of information capacity or density. The present invention achieves storage capacity of up to 1 kilobytes of memory within an area of one to four square inches. The significance of such a memory one should not be underestimated - it represents about 250 English words, about the size of a page or screen display. As an information unit, such unit is most suitable for many applications.

### 2.1 Summary of Label Row-Wise Organization

A two-dimensional label in according with the invention comprises multiple rows of codewords; that is, the term "label" is used here to mean a complex marking of specified dimensions that includes a number of codewords organized in rows. Each codeword is a mark pattern comprising a plurality of elements or marks; the marks can be of various heights, as in a bar code, or can be of a relatively small height to form a "dot code". Not just any mark pattern can constitute a codeword, however; each codeword belongs to a specific family or "set" of mark patterns that conforms to a particular descriptive rule about some characteristic of each mark pattern, e.g., a rule about the width of each mark and the total width of each mark pattern.

The codewords in any two adjacent rows are written in mutually exclusive subsets of the mark-pattern set (although in some embodiments the union of the subset is not exhaustive of the set itself). In particular, each subset of the mark-pattern set is defined so that it includes, as valid codewords for that subset, only those mark patterns that satisfy certain discriminator-function criteria.

Such rowwise usage of alternating subsets of codewords, grouped according to discriminator-function criteria, permits quick determination whether a row has been crossed, without the need for a horizontal guard bar. That is, for a given scanned codeword in a label, determination of the discriminator function indicates whether the codeword comes from the same row as the previously-scanned codeword or from a different row (that is, whether the scan line has crossed between rows as illustrated in Figure 1).

Detection of line-crossing permits "stitching" of partial scans of particular rows into a map (e.g., in

memory) of the label. The stitching process is roughly analogous to stitching a number of pieces of colored fabric into a predesigned quilt that displays, e.g., a picture: as each "piece" is required by the scanning process, it is incorporated piecewise into the appropriate point in the label.

For example, suppose that computation of the appropriate discriminator functions reveals that a scanning pass has scanned the first half of row 1 and the second half of row 2 of a label such as is shown in Figure 3. Assume that the respective longitude of the scanned data with respect to the ends of the label are known, e.g., through detection of start- and/or stop-codes. The knowledge that a row boundary has been crossed permits all the scanned data from the scanning pass to be incorporated into the respective proper rows of the label map at the respective proper longitudes (assuming no scanning or decoding errors); the data from the scanning pass need not be discarded merely because the data did not come from a single desired row.

As another (greatly simplified) hypothetical example, assume that a part of one row has been scanned and that the data "123456789" are incorporated into the label map as a result. Further assume that a second scanning pass of that row is made, and that the data "8789ABCD" are decoded as a result. If the overlapping portion if any between the two scanned data "pieces" - in this case, the "6789" portion - can be determined (e.g., with string-matching techniques such as described below), then the remainder of the later-scanned data can be appropriately incorporated into the label map (in this case, the "ABCD" portion).

Consequently, the operator need not be scrupulously careful to sweep the wand over the label one row at a time; virtually any scanning pass that includes either a row's start code or a stop code, or that can somehow be determined to overlap with data already incorporated in the label map, will yield usable data (assuming no coding or decoding errors). A label in accordance with the invention thus advantageously increases the density of information by permitting height reductions in the codewords.

## 2.2 Summary of Organization of Codeword Subsets

As noted, above, a key feature of the invention is the use of different codeword subsets in different rows, each subset satisfying certain discriminator-function criteria. In one embodiment described here for illustrative purposes, a (17,4) symbology is used. A discriminator function is used to divide the 11,400 available mark patterns in that symbology into three mark-pattern subsets of 929 codewords each.

The discriminator function may take as its inputs the various widths of the on- and off marks of a mark pattern (e.g., optically detectable bars and spaces) and may provide as an output a number from 0 to 8. Three subsets may then be selected whose discriminator function values are 0, 3, and 6, respectively, and whose mark widths meet certain other criteria. Each subset thus comprises a collection of codewords, all of whose discriminator functions are both equal to each other and readily distinguishable from those of the codewords in the other two subsets.

The availability of 929 codewords in each subset, each with a unique discriminatory-function number, permits each codeword to be used to represent a two-digit number in base 30. This capability leads to several advantages.

As shown in Figure 5, each digit of the two-digit base-30 number can be used in an "alpha mode" or in a "mixed mode"; that is, each digit can be mapped into a 30-place alphabetic translation table or into a 30-place mixed alphanumeric translation table. In each of these 30 place tables, one or more digits are reserved for use as signals to change translation tables.

Alternatively, each two-digit number can be used in a "numeric mode" or in a "user mode", that is, each number can be mapped into a 929-place numeric translation table or into any of up to twenty-seven 929-place user-defined translation tables. In each of these tables as well, one or more digits are reserved for use as signals to begin using a different translation table.

## 2.3 Summary of Two-Step Decoding Method

The decoding method of the invention advantageously makes use of the symbology organization of the invention. In the first step, when a codeword is scanned, the discriminator function of the scanned codeword is computed to determine the codeword subset of which the scanned codeword is a member. A t-sequence number based on the width of the marks comprising the codeword is also computed; that number is used as an entry point into a lookup table for the codeword subset in question. The lookup table yields a number from 0 to 928, which is parsed into a two-digit number in base 30.

In the second step, the high- and low-order digits of the base-30 number are used to determine the symbolic meaning assigned to the codeword (which may include an instruction to change translation tables).

The method of the invention thus advantageously permits the user to define multiple translation tables. In addition, the invention is not constrained by logical limits on the number of codewords per row nor on the number of rows. This gives the user freedom to lay out the symbology in areas of varying shapes.

## 5 2.4 Summary of Error Delection and Correction

A row-oriented incremental error detection capability is provided through the use of a checksum codeword for each row. After completion of low-level decoding but before performance of high-level decoding, various checksum computations are performed to test the accuracy of the scan.

- 10 In addition, a "final" checksum codeword for the label as a whole is used for additional security. The use of these checksums permits a limited degree of error recovery, since the checksums reflect the information contents of each of the codewords in the label. That is, errors in decoding particular codewords can be corrected in some circumstances by "subtracting" the known correct codewords from the checksum, so to speak, thereby yielding the correct value for the erroneously decoded codeword.
- 15 If the test results are satisfactory, the high-level decoding step is performed.

## 2.5 Summary of System Implementation

- Another feature of the present invention is to provide a system for reading bar code symbols or the like, including a hand-held scanning unit in a lightweight, portable housing including a symbol-detection device for generating a laser beam directed toward a symbol to be read, and for receiving reflected light from such symbol to produce electrical signals corresponding to data represented by the symbol; a data processing device for processing the data represented by the symbol having a state according to at least first and second different coding procedures; and a read-control device to actuate the symbol-detection device to
- 20 initiate reading of a symbol; wherein the symbol includes at least two groups of codewords; each codeword representing at least one information-bearing character and being selected from among a set of valid mark patterns. Each mark pattern comprises a pattern of marks, each mark pattern being representative of encoded data according to one of a plurality of different coding procedures; the codewords in each group being selected from a subset of mark patterns, the subset for said group being defined by a specified rule for that group that differs from the rule specified for said a different group; each coding procedure being a function of the state of the data processing device.
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- 30

## 3. Brief Description of the Drawings

- Figure 1A is an illustration of a prior-art bar code symbology.
- 35 Figure 1B is an illustration of a label in accordance with the present invention.
- Figure 2 is an illustration of the relationship between an x-sequence and a t-sequence in a codeword comprising part of a label embodying the present invention.
- Figure 3 is an exemplar layout of an illustrative high density two-dimensional symbology design in accordance with the invention.
- 40 Figure 4 is a block-diagram illustration of the use of alternate sub-symbologies in different rows of a multi-row label in accordance with the invention.
- Figure 5 is a table showing alternate translation modes for encoding or decoding codewords.
- Figure 6 is a state-machine diagram of aspects of a method for using the table shown Figure 5.
- Figure 7 is a pictorial representation of a sequence of encoding a string of readable characters into
- 45 scannable codewords.
- Figure 8 is a logic diagram of an illustrative circuit for computing a checksum for a row in a label embodying the invention; Figure 9 shows a similar circuit for computing an additional checksum for the entire label. Figure 10 is a schematic illustration of the layout of codewords within a label.
- Figures 11 through 13 are logic diagrams of illustrative circuits for performing error recovery in
- 50 accordance with the invention.
- Figures 14A through 14D, Figures 15A through 15D, and Figures 16A through 16D depict tables used for decoding codewords in three different sub-symbologies. Figure 17 is a C-language program that may be used to generate these tables.
- Figure 18 is a block diagram of a computer system using a nonvolatile electro-optical memory in
- 55 accordance with the invention.
- Figure 19a, 19b, 19c, and 19d is an alternative type of laser scanning pattern that may be used in connection with the present invention;
- Fig. 20 is an alternative arrangement of a bar code symbol; and

Fig. 21 is a cross-sectional view of an implementation of a hand-held laser scanner which may be used to implement the present invention.

#### 4. Detailed Description of Specific Embodiments

##### 4.1 Stitching of Partial Scans

The label of the invention proves especially useful for stitching together of partial scans. As noted above (and referring to Figure 1), when scan lines cross codeword rows in a label, the partial scans must be "stitched" or pieced together. For example, consider a retail store checkout counter where a sales clerk manually passes a hand-held wand over a multirow label. If the wand's travel does not run substantially parallel to the label, the scan line may pass from one row to another; parts of different rows are thus scanned, but neither row is scanned completely.

Stitching entails building a map of each row of the label (e.g. in memory); successive passes of the wand result in a greater degree of filling in the map. It can be accomplished by using known string matching algorithms, such as disclosed in D. Sankoff and J.B. Krushal, editors, *Time Warps, String Edits, and Macro-molecules: The Theory and Practice of Sequence Comparison*, Addison-Wesley, Reading, Massachusetts, 1983. One such algorithm is described below.

##### 4.2 Partitioned Symbolology

Stitching is facilitated by using different sub-symbolologies in alternate rows, selected so that the scanner can make a local decision on whether a row has been crossed. Using different sub-symbolologies in alternate rows allows the elimination of horizontal guard bars seen in prior-art code symbolologies, thus permitting higher density of information.

The illustrative embodiment of the present invention utilizes an advantageous scheme for organizing codewords into readily distinguishable groups. The scheme makes use of the principle of coding theorem to pick only a fraction of available mark patterns as legal code words to increase decoding reliability; it can be applied to any of a number of labels.

One such label, referred to here as a "PDF417" label (for "Portable Data File 417"), is described as an illustration of this invention. PDF417 is a (17,4) label of the (n,k) type described above. Each codeword has 4 bars and 4 spaces with a total width of 17 modules.

It can be shown that this code yields a set of 11,440 different combinations of mark patterns. To increase decoding reliability, only a fraction of these available mark patterns are used as valid codewords.

##### 4.3 Discriminator Function for Defining Subset Partition

As a first step in selecting a group of mark patterns for such use for this particular code, the 11,440 mark patterns are partitioned into nine subsets or "clusters," by calculating a discriminator function  $f(X)$  for each mark pattern  $X$ :

$$f(X) = (x_1 \cdot x_3 + x_5 \cdot x_7) \bmod 9$$

where  $x_1, x_3, x_5$  and  $x_7$  stand for the bars' widths, and  $x_2, x_4, x_6$  and  $x_8$  stand for the spaces' widths. The discriminator function  $f(X)$  above is one of possible alternative equations used to subdivide the different possible combinations into nine different subsets.

Further narrowing is performed on three of the nine subsets of mark patterns, namely the subsets in which  $f(X)=0$ ,  $f(X)=3$ , and  $f(X)=8$  (sometimes called cluster(0), cluster(3) and cluster(8), respectively). The narrowing is performed in part by defining a "t-sequence" for each mark pattern. Each element  $t_k$  of the t-sequence is computed according to the formula:

$$t_k = x_k + x_{k+1}, \text{ where } k = 1, \dots, 7$$

The three subsets cluster(i) (where  $i = 0, 3, 8$ ) are narrowed by selecting mark patterns where no mark width  $x_j$  is more than six (where  $j = 1, \dots, 7$ ), and where no  $t_k$  is more than nine (where  $k = 1, \dots, 7$ ).

Thus, the three final subsets cluster(i) of the mark patterns  $X$  that are selected for use as code words can be summarized as follows:

cluster(i) = {X : f(X) = i,  $x_j \leq 6$ ,  $t_k \leq 9$ }

where  $i = 0, 3, 6$ ,  $j = 1, \dots, 8$ , and  $k = 1, \dots, 7$ . After sorting each cluster by the t-sequence while suppressing duplicate entries, it can be shown that each cluster(i) includes at least 934 mark patterns. The closest prime number to 934 is 929; accordingly, 929 mark patterns are selected from each cluster(i) for use as codewords. (For convenience, the term "x-sequence," with respect to any given mark pattern, is defined as the number having as its digits  $x_1 x_2 \dots x_8$ .)

The t-sequence of each codeword can be used to identify that codeword, since it can be shown that each such t-sequence is unique within the three subsets cluster(i). It will be apparent that only the first six digits of the seven-digit t-sequence need be used to uniquely specify a codeword of the (17,4) type, since as illustrated in Figure 2, the value of the final t-sequence element  $t_7$  is completely determined by the first six elements  $t_1$  and the fixed total width  $\Sigma x_j$  of the mark pattern. As an example, suppose that  $t_1 = 2, t_2 = 4, t_3 = 6, t_4 = 7, t_5 = 6$ , and  $t_6 = 4$ ; the t-sequence for that codeword would be 246764.

The partition just described has the advantage that, by computing f(X) for any scanned mark pattern, the mark pattern's membership (or non-membership) in a codeword subset can quickly be ascertained. Furthermore, since the t-sequence for each codeword is unique, computation of the t-sequence permits that value to be used in a lookup table to determine the symbolic meaning assigned to a scanned mark pattern that belongs to a codeword subset.

Other equivalent discriminator functions f(X) may be constructed and used. Preferably, such a discriminator function should partition the available mark patterns into clusters (not necessarily nine clusters) approximately uniform in size. In addition, the clusters selected for use as codewords preferably are equidistant in "error distance"; that is, the probability that a codeword from any of selected clusters A, B, C, etc., will be mistaken for a codeword from another one of those clusters should be of the same order of magnitude regardless of which of the other clusters is considered.

#### 4.4 Generating Subsets of Codewords

An example of a computer program for generating lists of codewords for the various clusters(i) is set forth in Figure 17. The example program is written for convenience in the well-known C programming language, although any suitable language may be used; the example program is used generally as follows:

1. The program of Figure 17 is used to generate 9 output files, referred to here as out(i), where  $i = 0, \dots, 8$ . Only the output files out(0), out(3), and out(6) are used; they may be renamed as "cluster" files cluster(0), cluster(3), and cluster(6), respectively.
2. All three cluster files are conventionally sorted to remove ambiguous entries, i.e., to eliminate any mark pattern whose t-sequence is identical to the t-sequence of any other mark pattern.
3. The cluster files cluster(3) and cluster(6) are conventionally filtered to remove those entries in which any  $t_k$  is wider than 9.
4. In the cluster file cluster(0), those odd entries (i.e., the first entry, third entry, etc.) in which any  $t_k$  is wider than 6 are filtered out, as are those even entries in which any  $t_k$  is wider than 7. This is an arbitrary restriction designed to help make cluster(0) approximately the same size as cluster(3) and cluster(6), inasmuch as without such a restriction cluster(0) would be larger than the other two.
5. The first 929 t-sequences of each of the filtered cluster files are selected as the desired entries for the respective lookup tables.

#### 4.5 Multirow Label Using Alternating Codeword Subsets

In the multirow label of the invention, each row uses codewords from a different subset than the rows immediately adjacent to it. This enables the scanner to recognize with a high degree of precision whether a scan line has crossed a row in the middle of a codeword, because if a row has been crossed, the codewords scanned will not yield the same f(X) as the previous row.

A row of codewords in accordance with the invention may conveniently contain unique start and stop codes in the conventional manner whose x-sequences are, e.g., 81111113 and 71121113 respectively. These start and stop codes are unique in that no other codeword in any cluster has the same t-sequence as either of them; furthermore, they are members of none of the final subsets of codewords because the required condition  $x_j \leq 6$  for all  $j = 1, \dots, 8$  is not true for those codes. The start code may be selected to have its widest bar away from the ensuing data codewords to reduce the possibility of intercodeword interference, as is the above start code; if desired, the stop code may be so selected as well.

The height to unit module ratio H (the ratio of the height of a codeword (or a row) to one module width)

may be changed from label to label or even from row to row depending on the printing/scanner (system or channel) resolution, R, or on the need of various applications. Figure 3 shows the first and the last rows having H approximately equal to 10, the rows in between having H approximately equal to 3, and the resolution R being approximately equal to 10 mil.

5 The first row of the multirow label uses cluster(0) codes, the second row cluster(3) codes, the third cluster(6) codes, the fourth cluster(0) codes, the fifth cluster(3) codes, and so on. There is no logical limit on the number of codewords per row or the total number of rows.

In the embodiment illustrated here, the first codeword in each row is dedicated for use as a row identifier and the last codeword in each row is a checksum. (The maximum number of rows is thus 929, i.e., 10 the number of codewords in the dedicated cluster). It is of course possible to distinguish between forward scanning and backward scanning of the row by matching the start/stop codeword forwardly or backwardly.

#### 4.6 Other Row-Wise Partitioning of Codewords

15 It will be apparent to those of ordinary skill having the benefit of this disclosure that the invention is not limited to the specific mark patterns, discriminator function  $f(X)$ , and t-sequence described above. The foregoing method of deriving a symbology can be applied in a substantially similar manner to yield equivalent symbologies having other kinds of mark patterns.

For example, labels can be constructed from bars of varying shades of gray or even from bars of a 20 wide range of colors, instead of from black and white marks only. In such a label, a discriminator function for dividing all possible mark patterns into mutually exclusive codeword subsets and a t-sequence function for uniquely identifying each codeword within a subset, may be based on a readily detectable attribute of a mark such as its hue or its gray scale value as well as on the width of each mark (or in lieu of the width, or in combination with the width).

25 It will likewise be apparent that, broadly construed, the same principle encompasses the equivalent use of codewords of different colors (or shades of gray) in alternate rows. That is, all rows of a multi-row label could use the same subset of mark patterns as codewords, but in different colors or shades or orientations; the determination whether a row has been crossed would be made based on whether a color or shade or orientation change had occurred.

#### 4.7 Subset Organization for Two-Step Decoding

In the illustrative, width-based embodiment described above, since each cluster(i) includes 929 30 codewords, each t-sequence in a cluster thus will correspond to a number from 0 to 928. The codewords in 35 each subset can be organized according to a base 30 system in which one codeword, representing a number in base 30, is used to signify two alphanumeric characters.

Codewords can be scanned and decoded as follows. When a codeword is scanned, its t-sequence is noted. The t-sequence is then used as input to an initial, low-level decoding step; the output from the low-level decoding step is a number from 0 to 928 which in turn is used as an input to a high-level decoding 40 step.

#### 4.8 Initial Low-Level Decoding Step

The low-level decoding step entails looking up the t-sequence in a table for the appropriate cluster to 45 find a corresponding value. The table may be created as described above. Referring to Figure 14A (a lookup table for cluster(0)), for example, the t-sequence 246764 corresponds to the value 111.

The actual circuitry for the lookup tables may be conventional; it will be appreciated by those of ordinary skill that the use of a prime number of codewords in a subset, e.g., 929, advantageously facilitates the design of the circuitry.

#### 4.9 Mode-Dependent High-Level Decoding Step

The look-up value 111 from the foregoing example can be broken down into a two-number sequence in base 30, each number being in the range 0-29 and having a high-level value  $V_H$  and a low-level value  $V_L$ . 55 The base-30 sequence is computed as follows:

$$V_H = x \text{ div } 30; \text{ and} \\ V_L = x \text{ mod } 30.$$



For the t-sequence used above, 246764, yielding a look-up value of 111, the high level value is 3, and the low level value is 21, since  $111 = 3 \times 90 + 21$ . Each of the high and low values (i.e., 3 and 21) is then evaluated by looking it up in a suitable (arbitrary) table, such as shown in Figure 5.

The exemplar table in Figure 5 shows 30 decoding modes, including Alpha, Numeric, Mixed, and User modes. The various User modes are designated as the modes in Figure 5 corresponding to columns 3 through 29 (with column 0 being Alpha mode).

In the illustrative embodiment, the Alpha mode is the default mode; therefore, the sample t-sequence 246764 ultimately translates into the two-letter sequence DV, via the lookup value 111 and the base-30 sequence 3, 21.

It will be seen that the coding arrangement depicted in Figure 5 provides for mode switching that can be advantageously effected either within a single codeword or within a string of codewords. The technique for invoking mode switching varies depending on the current decoder mode.

#### 4.10 Examples of High-Level Decoding

The state machine diagram in Figure 6 illustrates a high-level decoding process in accordance with the invention for the exemplar embodiment. For convenience, a two-number sequence in base 90 is represented as "xxH xxL" or "(xxH,xxL)," where "xx" represents an arbitrary one- or two-digit number. For example, a high-level value of 18 and a low-level value of 10 is depicted herein as 18H, 10L or as (18H, 10L).

As an example, assume the decoder is currently in Alpha mode. As shown in Figure 5, changing from Alpha mode to Mixed mode requires that either the high value or the low value of the two-digit base-30 sequence be equal to 28. If the high value is 28, then the low value is unimportant for mode switching purposes; likewise, if the low value is 28, then the high value is unimportant for mode switching purposes.

For Alpha mode, a high value of 28 signals to the decoder that a mode switch to Mixed mode (depicted in Figure 5 as "ms" or Mixed-mode switch) must be effected; therefore, the low value of the high value/low value pair will be interpreted in the Mixed mode. A low value of 28 allows the decoder to interpret the high value of the high value/low value pair in the current mode, namely Alpha mode, and then to switch into Mixed mode. This mode switching technique allows a final value to be decoded in the current mode before switching to the next mode, therefore, eliminating waste resulting from using an extra high value/low value pair to insure that a final high value is interpreted in the current mode.

With decoding being done in Alpha mode, a hypothetical value of 856 yields 28H 16L, i.e., a high value of 28 and a low value of 16 (since  $856 = 28 \times 30 + 16$ ). The high value of 28 toggles the decoder into Mixed mode, and the low value 16, when translated according to Mixed mode protocol, yields "I" (an exclamation point).

To change from Alpha mode to User mode, a high value of 29 (depicted as "us" or User-mode switch) and any low value n within the range of 3 to 29 is required. Low values of 0, 1, or 2 result in no mode switch, a switch to Mixed mode, or a switch to Numeric mode, respectively. In contrast to switching from Alpha to Numeric or Mixed modes, a switch to a User mode cannot be done by a low value of 29; any such values are ignored.

Switching between other modes is done in a generally similar manner, as shown in Figure 5 and 6. Referring to those Figures, a decoder in Numeric mode can only directly switch to Alpha mode or Mixed mode. To toggle from Numeric mode to Alpha mode a non-position dependent value of 927 is required, i.e., either a high-level value or a low-level value equal to 927 will effect the mode switch. Likewise, to toggle from Numeric mode to Mixed mode a non-position dependant value of 928 is required. It will be apparent that the numbers 927 and 928 are the last two positions in the Numeric mode, and are reserved for mode-switching characters for convenience.

To change from User mode to one of the predefined modes (Alpha, Numeric or Mixed) a high value of 29 and a low value within the range 0 to 2 are required. The low value in this combination corresponds to the predefined mode into which the decoder is switching (i.e. a low value of 0 corresponds to Alpha mode, a low value of 1 corresponds to Mixed mode and a low value of 2 corresponds to Numeric mode).

For example, assume that the current mode is Alpha and that three consecutive codewords are to be decoded: 872, 345 and 99. Translating into base 30, 872 yields a high level value of 29 and a low level value of 2 ( $872 = 29 \times 30 + 2$ ). The first codeword 872 thus defines a User mode into which the decoder is switching. Referring to Figure 5, if the decoder is in Alpha mode and a high level value of 29 and a low level value of 2 are encountered (as in the example above), the decoder changes to Numeric mode.

As another example, assume that the decoder is in Alpha mode and that the scanned codeword's lookup value is 723. In this case  $V_H = 723 \text{ div } 30 = 24$ , and  $V_L = 723 \text{ mod } 30 = 3$ . Therefore, the decoded codeword is (24H,3L). Since the current mode is Alpha, Figure 5, yields (Y,D) as the respective values for the decoded codeword (24H,3L).

- 5     Decoding of values in the Numeric mode differs from decoding of values in Alpha mode and Mixed mode. Decoding in Numeric mode treats a two-number sequence as a number in base 926. For example, suppose that the current mode is Alpha and that the following three codewords are encountered 872, 345 and 99. A base 30 conversion of the first codeword 872 yields  $H=29$  and  $L=2$ . This sequence signals the decoder to switch from Alpha mode to Numeric mode. Switching to the radix-926 decoding system, the  
10    second and third codewords are decoded as  $(345 \times 926) + 99 = 319569$ .

- 15    The User modes may be used with considerable flexibility. All or part of one or more modes may be used to represent a special user-defined code; for example, frequently-occurring words, phrases, sentences, paragraphs, etc. can be assigned to respective positions within a User mode. A given phrase, etc., can then be represented in the label as a single codeword (combined with a "us" mode-switch command if necessary). It will be apparent that a great many different words, phrases, etc., can be represented, e.g., in the coding scheme depicted in Figure 5 as an illustration.

#### 4.11 Encoding Method

- 20    An encoding procedure is the reverse process of the decoding procedure. For example, referring to Figure 6, a license plate number "HUD-329" when encoded yields the following string of codewords: 230, 926, 843, 69. Each element of the original string "HUD-329" is located in Table 2 and translated according to proper mode protocol. The first four elements of the string are translated using Alpha mode. This results in  $H=7$ ,  $U=20$ ,  $D=3$ , and  $-$  (hyphen) = 26.

- 25    The last three elements may be translated using Mixed mode. To switch to Mixed mode from Alpha mode a Mixed Shift (28) character is needed. The Mixed-mode translation then results in  $3=3$ ,  $2=2$  and  $9=9$ . The complete string is thus 7 20 3 26 28 3 2 9.

- 30    This string is partitioned into high value/low value pairs, with resulting pairs (7,20) (3,26) (28,3) and (2,9). Each of these pairs is encoded as a codeword. To encode a high value/low value pair, the high value is multiplied by 30, and the low value is added to the result of this multiplication.

- 35    For example, the pair (7,20) is encoded by multiplying 7 times 30 and adding 20, yielding a result of 230. All four pairs are encoded in this manner; the resulting string is 230 116 843 69. The string is translated into codewords in accordance with the appropriate lookup table for the codeword subset in use. Assuming hypothetically that cluster(0) is in use, the string is expressed using the codewords corresponding respectively to t-sequences 335633 (for 230), 255663 (for 116), etc.

#### 4.12 Checksum Computation

- 40    A checksum and error recovery scheme provides a row-oriented incremental error detection capability and high primitive decoding reliability. Within each row, a long polynomial division checksum scheme is used.

- 45    For convenience, each i-th codeword may be referred to by a corresponding index number  $a_i$ , i.e., by the result of the low-level decoding step discussed above for that codeword. Each codeword's index number  $a_i$  will thus have a value from 0 to 928; each codeword is referred to sometimes for convenience by its index number.

Each row with codewords  $a_{n-1}, a_{n-2}, \dots, a_0$  can be represented as a polynomial:

$$a(x) = a_0 + a_1x + a_2x^2 \dots + a_{n-1}x^{n-1}$$

- 50    This polynomial is referred to herein as the message polynomial, as discussed in, e.g., Shu Lin & D.J. Costello, Jr., Error Control Coding, 1983.

A row checksum  $b_{n,0}$  is defined as the remainder resulting from dividing the message polynomial  $a(x)$  by a generator polynomial (see *Ibid.*):

$$55 \quad g_r(x) = x + 926$$

Those of ordinary skill will recognize that 926 is the complement of 3 in a Galois Field based on 929, or GF-(929).

The checksum of each row can conveniently be computed using the checksum encoding circuit shown in Figure 8. In Figures 8 through 13, the circle-plus (modulo addition), circle-X (modulo multiplication), and circle-C (modulo complementation) symbols are defined over GF(929) as:

- 6  $x \text{ (circle-plus) } y = (x + y) \bmod 929$   
 $x \text{ (circle-X) } y = (x * y) \bmod 929$   
 (circle-C)  $x = 929 - x$

where x and y are any numbers from 0 to 928. It will of course be recognized that the design and construction of actual circuitry is a matter of routine implementation by those of ordinary skill. Such circuitry consequently is not further discussed here.

To perform the checksum computation, the register  $b_{r0}$  is initialized to 0. The input is a sequence of the codewords' index numbers  $a_i$  in a row, fed one number at a time into the input. The input fans into the output line (e.g., to a label printer) and the checksum encoding circuit simultaneously.

- 15 As the first codeword is input, the circle-plus computation is performed with the codeword's number  $a_i$  sequence and  $b_{r0}$  (i.e., 0) as operands. The output of that computation and the number 926 is fed to the circle-X computation; the output of that computation is complemented and stored in the  $b_{r0}$  register. After all of the codewords in a row have been processed through the checksum encoding circuit, the complement of the final value of  $b_{r0}$  is the checksum and is appended at the end of the row. The sequence of codewords  
 20 for the row (e.g., as printed) is now  $a_{n-1}, a_{n-2}, \dots, a_0, 929-b_{r0}$ .

A similar scheme is used to compute a structure checksum, one representing the entire label. For this second type of checksum, all codewords in the label as printed (including the codewords representing the checksums for each row except the last row) form the message polynomial, which may be expressed as:

$$25 \quad a(x) = a_{m,2} + a_{m,3}x + \dots + a_{m,n-1}x^{n-3} \\ + b_{m-1,0}x^{n-2} + \dots + a_{1,n-1}x^{nm-3}$$

- where the coefficients are defined as in Figure 10, tracing backwardly from right to left and bottom to top. A  
 30 different generator polynomial is used to calculate a remainder in a similar fashion as before, namely:

$$g_s(x) = (x + 926)(x + 920)$$

- 35 Dividing the new message polynomial by this new generator polynomial results in a remainder  $b(x) = b_{a0} + b_{a1}x$ . Complementing the coefficients of this remainder yields two parity-check codewords, which serve as a structure checksum as discussed below.

In implementation, this division is accomplished by using a division circuit such as shown in Figure 9. The registers  $b_{a0}$  and  $b_{a1}$  are initialized as zeros. As soon as the message polynomial has entered the  
 40 output and the circuit, the complements of the parity-check codewords are in the registers and are appended in the order  $b_{a1}, b_{a0}$  just before the checksum of the last row. Then the checksum  $b_{r0}$  of the last row is computed and appended to the end of the last row, as shown in Figure 10.

It will be noted that there are no user-definable codewords corresponding to the positions  $a_{m,1}$  and  $a_{m,0}$ . These positions are reserved for the codewords  $b_{a,1}$  and  $b_{a,0}$  as shown in Figure 10. Thus, in a label with m  
 45 rows and n codewords per row, the total number of user-definable codewords is  $nm-4m-2$ , i.e., the number of codewords per row times the number of rows, minus four codewords for each row (a start code, a stop code, a row number, and a row checksum), and also minus the two parity-check codewords (i.e., the structure checksum).

#### 50 4.13 Gross Error Detection

Gross error detection may be accomplished as follows. At the beginning of the scanning process, all entries (e.g., "slots" or "grid locations") of the map of the label are initialized to indicate unknown characters.

- 55 The low-level decoding step, as applied to a signal generated by any given scanning pass, will generate a sequence of one or more index numbers, one for each codewords that was scanned. Each index number may be any number from 0 to 928, depending on the t-sequence of the corresponding scanned codeword.

For each scanning pass, three arrays DA, CA, and FA are constructed (e.g., in memory in accordance

with conventional techniques) to represent the codewords scanned in that pass:

- A "decoding array" DA represents the index numbers that are obtained from the tables in Figures 14A through 16D and that correspond to the scanned codewords.
- A "cluster array" CA represents the clusters or subsets to which the respective scanned codewords belong.
- A "confidence array" FA represents the confidence existing in the accuracy of the decoding of the respective scanned codewords.

For example, a scanning pass and low-level decoding step may generate a decoding array DA comprising a sequence of index numbers such as (293, 321, 209, 99, 879). The corresponding sequence of clusters might be (3, 3, 0, 0, 0) indicating that the first two codewords were members of cluster(3) and the final three were members of cluster(0). This implies that the subsequence comprising the second and third codewords (represented by 321 and 209 in the array DA) bracket the point at which a row was crossed, i.e., that the two codewords are in two adjacent rows. Because such row-crossing subsequences frequently have higher error probability, they are assigned a relatively low weight in a confidence array FA. In the example above, the confidence array FA for the scanned codewords might be (3, 1, 1, 3, 3).

Now suppose that a previous scanning pass had resulted in a decoding array DA of (293, 329, 222, 999, 999) for the same sequence of codewords, where 999 represents an unknown codeword whose confidence level is zero. Further assume that the confidence array FA for that previous scanning pass is (3, 3, 1, 0, 0), because the row was crossed between the third and fourth characters on that pass instead of between the second and third characters as hypothesized in the previous paragraph.

A "voting" process may be used to compare the confidence arrays for the two scanning passes to determine which results are more likely to be correct. For example, the voting rules may be as follows:

1. If two successive scans of a given codeword result in the same index number after low-level decoding, then the corresponding confidence figures in the two confidence arrays FA are added;
2. In contrast, if two successive scans result in different numbers for the same codeword, then (a) if one of the two index numbers has a higher confidence level than the other, the higher-confidence index number "survives" and is filled into the decoding array DA, but the confidence level for the corresponding position in the confidence array FA is reduced by the confidence level for the nonsurviving index number, (b) if both index numbers have equal confidence levels, then neither index number survives; instead the unknown-codeword index number 999 is used as the "surviving" index number and the confidence is reset to zero; and
3. If the index number  $a_i$  for one scan of a given codeword 999 (representing an unknown codeword) and an acceptable index number for the other scan (i.e., an index number from 0 to 928), then the acceptable index number is kept, and the confidence level of that index number remains the same.

It will of course be appreciated by those of ordinary skill that a wide variety of conventional array- and memory-management technique may be used for creating and manipulating the arrays DA, CA, and FA. For example, the decoding array DA might be the label map itself, with a temporary array being used to hold the index numbers  $a_i$  for a new scan and with surviving index numbers from that scan being written into the appropriate position in the array DA (or perhaps not written if the same index number is already represented at that position). In such an example, the cluster array CA and the confidence array FA might each be "shadows" of the decoding array DA, with as many positions in each as there are in the decoding array DA.

When the decoding array DA has been filled with an acceptable index number  $a_i$  for all codeword positions corresponding to a particular row in the label, the representation of that row in the decoding array DA is set aside. That is, regardless of the confidence that exists about the accuracy of the contents of the decoding array DA, once the row has been decoded to indicate acceptable index numbers for each codeword, no further decoding is done for codewords in that row; additional error detection proceeds as described below.

#### 4.14 Further Error Detection and Recovery by Checksumming

Errors may still exist in the decoding array DA for a particular row even after that row is set aside. Before performing high-level decoding, the redundant information stored in the row checksums and the label checksum can advantageously be used to detect and/or recover from errors in scanning any particular codeword by a process of elimination.

Generally speaking, if all but one or two of the codewords in the entire label are known to be correct, the correct values of the unknown codewords can be computed by "subtracting" (so to speak) the values of the known codewords from the values of the checksums, which of course reflect the values of all codewords, known and unknown.

Errors in any particular row may be detected by using a syndrome divider such as shown in Figure 11. The register  $d_{r0}$  is initialized to zero. After the index numbers  $a_i$  of the scanned row are fed to the syndrome divider, the register  $d_{r0}$  indicates the detection result. If  $d_{r0}$  is equal to zero, the corresponding row was correctly scanned and its image or map in memory can be locked; otherwise, an error occurred in the scanning and decoding of the row, and the row must be rescanned. If all codewords in the label are decoded and check summed without error, then the following error recovery step can be skipped.

When the total number of still-unknown codewords is less or equal to two, an error recovery scheme as follows can be invoked. The unknown codewords first are replaced in the label map with zeros. A syndrome  $S_i$  is then computed for each  $i = 1, 2$ . Since by hypothesis the position  $p_v$  of the unknown (i.e., erroneous) codewords is known, where  $v = 1, 2$ , only the values of those unknown codewords need be computed. As a first step, an errors value  $e_{pv}$  is computed for each error position  $p_v$  by solving the following system of matrix equations:

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} 3^{p1} & 3^{p2} \\ 3^{2(p1)} & 3^{2(p2)} \end{bmatrix} \begin{bmatrix} e_{p1} \\ e_{p2} \end{bmatrix}$$

If only one error exists, the system becomes overdetermined, that is, more information is present than is needed to solve the above matrix, which reduces to:

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} 3^{p1} \\ 3^{2(p1)} \end{bmatrix} e_{p1}$$

For an assumed one-error case, if the above matrix equation system is consistent (that is, if the foregoing two matrix equations yield the same solutions), then one error does indeed exist and the solution of  $3^{p1}$  is the error value, i.e., the correct value of the unknown codeword. Otherwise, an undiscovered second error exists in the label, and the decoding result is rejected.

After successfully solving for the error values, the complement of error values, are filled into the corresponding unknown codewords' locations. Then the error detection computation is performed again for those rows containing unknown codewords. If no errors are detected, the decoding result then is taken as correct; otherwise, the decoding result is likewise rejected.

#### 4.15 Nonvolatile Memory and Computer System

Referring to Figure 18, a nonvolatile electro-optical memory 100 may be created by marking a suitable substrate (e.g., paper) with one or more labels in accordance with the foregoing description. The memory 100 may be combined with a fixed or movable scanner 110 for use as a storage device for a suitably programmed computer such as a processor 120.

For example, a robot might have an on-board computer programmed to control the robot to perform simple tasks, such as selectively moving an object 130 by means of a manipulator 140. An on-board scanner 110 might operate as the robot's "eyes" for reading labels of the kind described above. In similar fashion, a conveyor system might include a fixed scanner 130 and a moving belt that served as the manipulator 140. The label preferably contains a list of instructions for operating the robot, with the computer on-board. The robot responding to data and instructions contained on the label.

It will of course be recognized by those of ordinary skill (having the benefit of this disclosure) that the invention is capable of being adapted to other uses and in other embodiments than the illustrative ones disclosed above. Furthermore, the invention may be implemented in numerous specific architectures. A few examples are briefly mentioned below for illustrative purposes:

- The decoder of a conventional one-dimensional scanner could be reprogrammed to perform one or more of the functions described above, e.g., by replacing a read-only memory (ROM) chip containing the programming if the scanner is so constructed;
- A scanning system could be built using a suitably programmed microprocessor or other computational unit to perform one or more of the above functions. The programming could be loaded into

dynamic read-write memory (RAM), or could be "burned" into read-only memory (ROM) either onboard or outboard of the microprocessor;

- A scanning system could be built using a computation unit specially designed to perform the functions described above;
- 5 • Parallel processing technology could be used to partition the work of decoding the various parts of a label; and so forth. The actual design and construction of any particular implementation is a matter of routine for those of ordinary skill having the benefit of this disclosure, the details of which are not further discussed here.

Referring to Figure 18, a computer system including a nonvolatile memory 100 of the type described  
 10 could be used in a number of applications. As an illustration, an overnight package delivery service (e.g., Federal Express, UPS, Purolator, and the like) might have certain of its package-sorting functions automated through the use of memories 100 in the form of printed labels in accordance with the foregoing, applied to packages such as the object 130 shown in the figure. In one such possibility, package shippers would fill out a waybill 100 by responding to queries posed by a suitable computer program. The program's printed  
 15 output (e.g., on a laser printer or dot matrix printer) might include both a human-readable destination address and a label 100 as described above in which that information was encoded in scannable form. The shipper would affix the waybill 100 to the object 130 being shipped. (Other information such as the shipper's telephone number and the like could likewise be so encoded.) One of the key advantages of the high data capacity memory 100 of the present invention is that it may be created at the warehouse or  
 20 loading dock by an inexpensive printer so that updated or corrected information may be applied at the point of shipment. The fact that the memory is merely a paper label means that it is inexpensive and disposable. Thus, the present invention may be implemented in conjunction with a portable terminal and thermal printer to create and print a label, even in a remote location. Such a portable terminal, connected to scanner, allows the user to scan, print, and apply the label to the article quickly and inexpensively. At various points during  
 25 shipment, suitable robots could read the label 100 and, using manipulators 140, direct the object 130 appropriately; e.g., a scanner 110 could read the memory 100 to generate a signal; based on the content of that signal, a manipulator 140 controlled by a processor 120 could move the object 140 as appropriate.

A similar arrangement could be used in a warehouse inventory control system. A label of the type described could be printed or otherwise applied to or inscribed on one or more sides of a shipping carton or  
 30 directly to merchandise. The label might have encoded therein as much information as desired about the specific item, e.g., its type, color, dimensions, weight, point of manufacture, lot number, and so forth. A suitable robot could be used as an order-filling machine by moving within the warehouse and, using its scanner, searching for merchandise whose label indicates that it matches a specified order. (Searching could of course be in accordance with techniques now known or hereafter developed.) It will be apparent  
 35 that this arrangement would permit information about specific merchandise items to be stored locally at the merchandise itself.

Another feature of the present invention is to utilize the bar code according to the present invention so that it may be affixed to an article as a means of identifying that article and associating information with the article much like a "read-only memory" or identification tag implemented in so called RF ID systems. One  
 40 such implementation is to print a variety of different bar code symbols which are available in easily disposable and affixable format so that information may be easily and quickly affixed to the article. One example of an application is in connection with the repair and service of equipment. The use of a service record is useful for quality control and documentation purposes, but it is often impractical to store detailed written records with the equipment. The use of a high density, encoded service report affixed to the  
 45 equipment in the form of a two dimensional bar code is especially advantageous. The service technician may select the appropriate PDF label from a set of labels corresponding to repairs performed, and attach the label to the repaired equipment. If the equipment is returned for subsequent repairs, the service technician has the complete service history attached to the equipment in only a few square inches.

Such local storage could advantageously take the place of a separate file of information about the item,  
 50 e.g., stored in a computer data base and keyed to a bar-code serial number on the item. Local storage would reduce the problem of dealing with "orphan" merchandise whose serial numbers were not known to the computer data base. In addition, it would permit rapid in-processing of newly-received merchandise shipments, in that complete information about the new merchandise could be scanned into the warehouse's information system, obviating the need for the shipper to generate and transmit a separate information file  
 55 (e.g., on a computer tape or by hard copy) about the specific items being shipped. This would similarly be advantageous in, e.g., libraries or other organizations that regularly received shipments of books or similar objects that required cataloging.

As another example, a nonvolatile memory and scanner system could be used for enhanced searching

of microfilm rolls or microfiche sheets. Assume that a large body of text and/or graphical information is stored photographically on a roll of microfilm. An example of such information might be the thousands of documents - printed, typed, handwritten, drawn, or a combination thereof - that can be involved in a large litigation. Known computerized litigation support systems permit paralegals to summarize each document  
 5 page in a data base; for each document page, selected information from the data base could be inscribed as a label in accordance with the foregoing on the corresponding frame of microfilm, in a corner or other appropriate location.

A microfilm reader could be equipped with (a) input means such as a keyboard by which a user could specify search criteria (e.g., in Boolean logic); (b) a fixed scanner to read microfilm labels as the microfilm  
 10 was scrolled; and (c) control means to determine whether a given microfilm frame satisfied the specified search criteria. The user would then be able to view documents conveniently. In the case of multiple-reel document collections, a master index or indexes could be encoded on a separate reel; output means such as a CRT or an LCD or LED display could be used to instruct the user as to which reel to mount to locate the specific document desired.

For example, a microfilm reader with a scanner might be designed to be coupled to and controlled by a  
 15 conventional desktop, laptop, or notebook computer in a conventional manner as a peripheral device (or the essentials of such a computer could be built into the reader). The computer would not need to have the entire document-summary data base available on disk storage, since the microfilm itself would contain the necessary information; it would suffice if the computer was programmed (e.g., in ROM) to perform the  
 20 desired search functions using the label-encoded data from microfilm.

Still another feature of the present invention is to provide a method for processing information by optically scanning indicia on the surface of a substrate, the indicia including a plurality of codewords scanned sequentially and organized into at least two independent scanning paths, each codeword being either an information codeword or a control codeword, and each information codeword corresponding to at  
 25 least one information-containing character. A plurality of different mapping functions are provided each associating the code word with one character out of a set of different characters, with only one mapping function being active at any given time. Each codeword in any one scanning path is distinct from any codeword in an adjacent scanning path. Using such a codeword data structure, the method includes the steps of: determining whether a scanned codeword is an information codeword or a control codeword;  
 30 decoding the codeword according to the mapping function if said codeword is an information codeword; and processing the codeword if the codeword is a control codeword. If the codeword is a control codeword, it identifies a new mapping function, and processing of subsequently scanned codewords take place using the new mapping function.

As an example of the different scanning paths that may be used, and a different organization of the  
 35 codewords, reference is made to Figures 19 and 20.

Figure 19a, 19b, 19c, and 19d is an alternative type of laser scanning pattern that may be used in connection with the present invention.

The present invention may be implemented in a hand-held, laser-scanning, bar code reader unit such as illustrated in Figure 21. This hand-held device of Figure 21 is generally of the style disclosed in U.S.  
 40 Patent 4,760,248, issued to Swartz et al, assigned to Symbol Technologies, Inc., and also similar to the configuration of a bar code reader commercially available as part number LS 8100II from Symbol Technologies, Inc. Alternatively, or in addition, features of U.S. Patent 4,387,297 issued to Swartz et al, or U.S. patent 4,409,470 issued to Shepard et al, both such patents assigned to Symbol Technologies, Inc., may be employed in constructing the bar code reader unit of Figure 21. These patents 4,760,248, 4,387,297  
 45 and 4,409,470 are incorporated herein by reference. A outgoing light beam 151 is generated in the reader 100, usually by a laser diode or the like, and directed to impinge upon a bar code symbol a few inches from the front of the reader unit. The outgoing beam 151 is scanned in a fixed linear pattern, or more complex pattern such as shown in Figure 19 may be employed and the user positions the hand-held unit so this scan pattern traverses the symbol to be read. The use of a central dark portion, such as in Fig. 19d, may be  
 50 used for aiming, or other visual techniques associated with alignment. Reflected light 152 from the symbol is detected by a light-responsive device 148 in the reader unit, producing serial electrical signals to be processed for identifying the bar code. The reader unit 100 is a gun shaped device, having a pistol-grip type of handle 153 and movable trigger 154 is employed to allow the user to activate the light beam 151 and detector circuitry when pointed at the symbol to be read, thereby saving battery life if the unit is self-  
 55 powered. A lightweight plastic housing 155 contains the laser light source, the detector 148, the optics and signal processing circuitry, and the CPU 140 as well as a battery 162. A light-transmissive window 156 in the front end of the housing 155 allows the outgoing light beam 151 to exit and the incoming reflected light 152 to enter. The reader 100 is designed to be aimed at a bar code symbol by the user from a position

where the reader 100 is spaced from the symbol, i.e., not touching the symbol or moving across the symbol. Typically, this type of hand-held bar code reader is specified to operate in the range of perhaps several inches.

As seen in Figure 21, a suitable lens 157 (or multiple lens system) is used to collimate and focus the scanned beam into the bar code symbol at an appropriate reference plane, and this same lens 157 may be used to focus the reflected light 152. A light source 158 such as a semiconductor laser diode is positioned to introduce a light beam into the axis of the lens 157 by a partially-silvered mirror and other lenses or beam-shaping structure as needed, along with an oscillating mirror 159 which is attached to a scanning motor 160 activated when the trigger 154 is pulled. If the light produced by the source 158 is not visible, an aiming light may be included in the optical system, again employing a partially-silvered mirror to introduce the beam into the light path coaxially with the lens 157. The aiming light, if needed, produces a visible-light spot which is scanned just like the laser beam; the user employs this visible light to aim the reader unit at the symbol before pulling the trigger 154.

In real applications, either the length of bar code should be fixed, or an additional character should be placed in the bar code to indicate its length. If not, misdecodings may occur.

If the length of the bar code is fixed, the performance of decoding using stitching might be better than that of decoding using a complete scan, because the reject rate and the misdecode rate is less in most good quality bar code (in cases that the quality of the bar code is very very poor, the misdecode rate may be greater, but never greater than 2K times, K is the number of the scans used for stitching).

Although the present invention has been described with respect to multiple line bar codes, it is not limited to such embodiments. It is conceivable that the method of the present invention may also find application for use with various machine vision or optical character recognition applications in which information is derived from other types of indicia such as characters or from the surface characteristics of the article being scanned.

In all of the various embodiments, the elements of the scanner may be assembled into a very compact package that allows the scanner to be fabricated as a single printed circuit board or integral module. Such a module can interchangeably be used as the laser scanning element for a variety of different types of data acquisition systems. For example, the module may be alternately used in a hand-held scanner, a table top scanner attached to a flexible arm or mounting extending over the surface of the table or attached to the underside of the table top, or mounted as a subcomponent or subassembly of a more sophisticated data acquisition system.

The module would advantageously comprise a laser/optics subassembly mounted on a support, a scanning element such as a rotating or reciprocating mirror, and a photodetector component. Control or data lines associated with such components may be connected to an electrical connector mounted on the edge or external surface of the module to enable the module to be electrically connected to a mating connector associated with other elements of data acquisition system.

An individual module may have specific scanning or decoding characteristics associated with it, e.g. operability at a certain working distance, or operability with a specific symbology or printing density. The characteristics may also be defined through the manual setting of control switches associated with the module. The user may also adapt the data acquisition system to scan different types of articles or the system may be adapted for different applications by interchanging modules on the data acquisition system through the use of the simple electrical connector.

The following claims are intended to encompass all such uses, implementations, and embodiments.

#### 45 Claims

##### 1. A data file structure that includes:

- (a) at least two rows of codewords, one row adjacent to and beneath another row;
- (b) each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns;
- (c) each said mark pattern comprising a pattern of marks, each said mark being representative of one of a plurality of different states;
- (d) the codewords in each said row being selected from a subset of said mark patterns, the subset for said row being defined by a specified rule for that row that differs from the rule specified for said adjacent row;
- (e) each said rule being a function of a detectable characteristic of the respective said marks.

##### 2. A data file structure as set forth in claim 1 in which each said mark pattern includes a pattern of marks



of varying optical reflectivity.

3. A data file structure as set forth in claim 1 in which each said mark pattern includes a pattern of alternating reflecting and nonreflecting
- 5 4. A data file structure as set forth in claim 1 in which each said mark pattern includes a pattern of magnetically detectable marks.
6. A data file structure as set forth in claim 1 in which each said rule partitions the set of detectable mark patterns into a plurality of subsets of equidistant error distance.
- 10 7. A data file structure as set forth in claim 1 in which each said rule is a function of the respective widths of the said marks.
- 15 8. A data file structure as set forth in claim 1 in which each said subset includes only codeword whose said marks are of respective widths not greater than a specified upper width limit.
8. A data file structure as set forth in claim 1 in which:
  - (a) said data file structure includes at least three rows of said codeword;
  - 20 (b) said respective subsets include only codewords  $X$  whose  $x$ -sequence functions  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  are equal to respective preselected values,
  - (c) each  $x_i$  for a codeword representing the width of an  $i^{\text{th}}$  mark of the codeword.
9. A data file structure as set forth in claim 6 in which:
  - 25 (a) said respective subsets include only codewords  $X$  whose  $t$ -sequences  $t_i = x_i + x_{i+1}$  are not greater than 9,
  - (b) each  $x_i$  of a codeword representing the width of an  $i^{\text{th}}$  mark of the codeword.
10. A data file structure including:
  - 30 (a) at least three rows of codewords, including a second row adjacent to and disposed between each of a first row and a third row;
  - (b) each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark
  - 35 patterns; (c) each said mark pattern comprising a pattern of marks, each said mark being representative of exactly one of two different states;
  - (d) the codewords in each said row being selected from a subset of said mark patterns; (e) each respective said subset including only codewords  $X$  whose said marks are of respective widths not greater than a specified upper width limit, whose  $x$ -sequence functions  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 8$  are equal to 0, 3, or 8, respectively, and whose  $t$ -sequences  $t_i = x_i + x_{i+1}$  are not greater
  - 40 than 9,
  - (f) each  $x_i$  for a codeword representing the width of an  $i^{\text{th}}$  mark of the codeword.
11. A nonvolatile read-only memory including a substrate on which is inscribed a data file structure in accordance with any one of claims 1 through 10.
- 45 12. An electro-optical computer including:
  - (a) a nonvolatile read-only memory including a substrate on which is inscribed a data file structure in accordance with any one of claims 1 through 10;
  - (b) scanning means for generating a signal responsive to said memory; and
  - 50 (c) processing means responsive to said signal.
13. A robotic system for use in selectively moving an object that includes a data file structure in accordance with any one of claims 1 through 10, including:
  - (a) scanning means for generating a signal responsive to said data file structure; and
  - 55 (b) means for manipulating said object in response to said signal.
14. A method of generating a signal representative of information encoded in a data file structure, said data file structure including at least two rows of codewords, one row adjacent to and beneath

- another row,  
 each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns,  
 each said mark pattern having a determinable discriminator function value and comprising a pattern of marks, each said mark being representative of one of a plurality of different states,  
 the codewords in each said row being selected from a subset of said mark patterns whose discriminator function values satisfy a rule for that row that differs from the rule specified for the other said row,  
 said method including the steps of:
- (a) scanning a codeword;
  - (b) computing the discriminator function for the codeword;
  - (c) determining, from the value of the computed discriminator function, the row in which the codeword is present;
  - (d) decoding the codeword to obtain a corresponding symbolic value; and
  - (e) generating a signal representative of the presence of said corresponding symbolic value in the determined row.
15. A method of generating a signal representative of information encoded in a data file structure, said data file structure including first, second, and third rows of codewords, each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns,  
 each said mark pattern comprising a pattern, of fixed width, of marks of varying widths representing on states and off states,  
 each said mark having a width  $x_i$  of an integral multiple of a width unit,  
 each of said first, second, and third subsets including only codewords  $X$  matching all of the following criteria: namely (i) the  $x$ -sequence function  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  of each codeword  $X$  in the respective first, second, and third subsets, is equal to 0, 3, or 6, respectively, (ii) all  $t$ -functions  $t_i = x_i + x_{i+1}$  of each codeword  $X$  are not greater than 9, and (iii) each codeword  $X$  includes only marks whose widths are not greater than 6,  
 said method including the steps of:
- (a) performing a scan of a mark pattern within said structure and generating an electronic image of said scanned mark pattern;
  - (b) determining whether said scanned mark pattern is a codeword;
  - (c) if the scanned mark pattern is a codeword, then classifying the codeword as a member of one of the first, second, or third subsets;
  - (d) decoding the scanned codeword; and
  - (e) generating a signal uniquely representing the scanned codeword.
16. A method as set forth in claims 15 in which said step of determining whether said scanned mark pattern is a codeword includes the steps of:
- (a) computing a  $t$ -sequence of  $N-1$  digits whose  $i^{\text{th}}$  digit is  $t_i$ , where  $N$  is the number of marks in the scanned mark pattern;
  - (b) computing the  $x$ -sequence of the scanned mark pattern; and
  - (c) if the computed  $t$ -sequence and the computed  $x$ -sequence fail to satisfy the criteria for said first, second, and third subsets, then indicating that the scanned mark pattern is not a codeword.
17. A method of generating a signal representative of information encoded in a data file structure, said data file structure including first, second, and third rows of codewords, each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns,  
 each said mark pattern comprising a pattern, of fixed width, of marks of varying widths representing on states and off states,  
 each said mark having a width  $x_i$  of an integral multiple of a width unit,  
 each of said first, second, and third subsets including only codewords  $X$  matching all of the following criteria: namely (i) the  $x$ -sequence function  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  of each codeword  $X$  in the respective first, second, and third subsets is equal to 0, 3, or 6, respectively, (ii) all  $t$ -functions  $t_i = x_i + x_{i+1}$  of each codeword  $X$  are not greater than 9, and (iii) each codeword  $X$  includes only marks whose widths are not greater than 6,  
 said method including the steps of:

- (a) performing a scan of a mark pattern within said structure and generating an electronic image of said scanned mark pattern;
- (b) computing a t-sequence of N-1 digits whose  $i^{\text{th}}$  digit is  $t_i$  where N is the number of marks in the scanned mark pattern;
- 5 (c) computing the x-sequence of the scanned mark pattern; and
- (d) if the computed t-sequence and the computed x-sequence fail to satisfy the criteria for said first, second, and third subsets, then indicating that the scanned mark pattern is not a codeword.
- (e) if the scanned mark pattern is a codeword, then classifying the codeword as a member of one of the first, second, or third subsets;
- 10 (f) obtaining from a lookup in a memory an index number that, for all t-sequences within the first, second, and third subsets, uniquely corresponds to the computed t-sequence;
- (g) converting the index number into a two-digit number in base 30, said number having a high value and a low value;
- (h) for each of the high value and the low value in succession, (1) determining, from the state of a decoding-mode variable stored in a memory, which of a plurality of decoding modes is a current active decoding mode, (2) determining a symbol character associated with the high value or low value from the table in Figure 5 associated with the active mode, and (3) if the said symbol character is a shift character, changing to a specified new current decoding mode; and
- 15 (i) generating a signal uniquely representing the scanned codeword.
- 20 18. A method of generating a signal representative of information encoded in a data file structure, said data file structure including first, second, and third rows each comprising a plurality of codewords, each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns,
- 25 each said mark pattern comprising a pattern, of fixed width, of marks of varying widths representing on states and off states,
- each said mark having a width  $x_i$  of an integral multiple of a width unit,
- each of said first, second, and third subsets including only codewords X matching all of the following criteria: namely (i) the x sequence function  $f(X) = (x_1 \cdot x_3 + x_5 \cdot x_7) \bmod 9$  of each codeword X in the respective first, second, and third subsets is equal to 0, 3, or 6, respectively, (ii) all t-functions  $t_i = x_i + x_{i+1}$  of each codeword X are not greater than 9, and (iii) each codeword X includes only marks whose widths are not greater than 6,
- 30 each said row including a codeword representing a checksum of the other codewords in the row, the checksum being a function of unique respective values of each codeword in the row,
- 35 said method including the steps of:
- (a) performing a scan of a mark pattern within a said row and generating an electronic image of said scanned mark pattern;
- (b) computing a t-sequence of N-1 digits whose  $i^{\text{th}}$  digit is  $t_i$ , where N is the number of marks in the scanned mark pattern;
- 40 (c) computing the x-sequence of the scanned mark pattern; and
- (d) if the computed t-sequence and the computed x-sequence fail to satisfy the criteria for said first, second, and third subsets, then indicating that the scanned mark pattern is not a codeword.
- (e) if the scanned mark pattern is a codeword, then classifying the codeword as a member of one of the first, second, or third subsets;
- 45 (f) obtaining from a lookup in a memory an index number that, for all t-sequences within the first, second, and third subsets, uniquely corresponds to the computed t-sequence;
- (g) storing said index number for the scanned codeword in a corresponding storage location in a decoding array DA in a memory;
- (b) storing a confidence-level value for the scanned codeword in a confidence array FA;
- 50 (i) if an index number has been stored in the decoding array DA for all codewords in the said row, then computing the checksum function of the codewords represented in the decoding array DA;
- (j) if the computed checksums does not match the checksum codeword for the row, then indicating an error;
- 55 (k) if the computed checksum does match the checksum codeword for the row then (1) converting each index number into a two digit number in base 30, said number having a high value and a low value, (2) for each of the high value and the low value in succession, (i) determining, from the state of a decoding-mode variable stored in a memory, which of a plurality of decoding modes is a currently active decoding mode, (ii) determining a symbol character associated with the high value

or low value from the table in Figure 5 associated with the active mode, and (iii) if the said symbol character is a shift character, changing to a specified new current decoding mode, and (3) generating a signal uniquely representing the scanned codeword.

- 5 19. A method of generating a signal representative of information encoded in a data file structure, said data file structure including first, second, and third rows each comprising a plurality of codewords, each said codeword representing at least one information-bearing character and being selected from among a set of detectable mark patterns,
- 10 each said mark pattern comprising a pattern, of fixed width, of marks of varying widths representing on states and off states,
- each said mark having a width  $x_i$  of an integral multiple of a width unit,
- each of said first, second, and third subsets including only codewords  $X$  matching all of the following criteria: namely (i) the  $x$ -sequence function  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  of each codeword  $X$  in the respective first, second, and third subsets is equal to 0, 3, or 6, respectively, (ii) all  $t$ -functions  $t_i = x_i + x_{i+1}$  of each codeword  $X$  are not greater than 9, and (iii) each codeword  $X$  intrudes only marks whose widths are not greater than 6,
- 15 each said row including a codeword representing a checksum of the other codewords in the row, the checksum being a function of unique respective values of each codeword in the row,
- the data file structure including a sequence of one or more codewords representing a structure checksum,
- 20 said method including the steps of:
- (a) performing a scan of a mark pattern within a said row and generating an electronic image of said scanned mark pattern;
  - (b) computing a  $t$ -sequence of  $N-1$  digits whose  $i^{\text{th}}$  digit is  $t_i$ , where  $N$  is the number of marks in the scanned mark pattern;
  - (c) computing the  $x$ -sequence of the scanned mark pattern; and
  - (d) if the computed  $t$ -sequence and the computed  $x$ -sequence fail to satisfy the criteria for said first, second, and third subsets, then indicating that the scanned mark pattern is not a codeword.
  - (e) if the scanned mark pattern is a codeword, then classifying the codeword as a member of one of the first, second, or third subsets;
  - (f) obtaining from a lookup in a memory an index number that, for all  $t$ -sequences within the first, second, and third subsets, uniquely corresponds to the computed  $t$ -sequence;
  - (g) storing said index number for the scanned codeword in a corresponding storage location in a decoding array DA in a memory;
  - (h) storing a confidence-level value for the scanned codeword in a confidence array FA;
  - (i) repeatedly performing steps (a) through (h) until an index number has been stored in the decoding array DA for (i) the row checksum codeword for the said row and the structure checksum codeword sequence, and (ii) all but at most two of all codewords in all rows of the data file structure;
  - (j) if an index number has not been stored for an unknown codeword in said row, then computing an index for said unknown codeword as a function of one or both of the index numbers for the row checksum codeword and the structure checksum codeword sequence;
  - (k) if an index number has been stored in the decoding array DA for all codewords in the said row, then computing the checksum function of the codewords represented in the decoding array DA;
  - (l) if the computer checksum does not match the checksum codeword for the row, then indicating an error.
- 45
20. A method as set forth in claim 19 including the additional steps, if the computed checksum does not match the checksum codeword for the row, of:
- (a) converting each index number into a two-digit number in base 30, said number having a high value and a low value;
  - (b) for each of the high value and the low value in succession, (i) determining from the state of a decoding-mode variable stored in a memory, which of a plurality of decoding modes is a currently active decoding mode, (ii) determining a symbol character associated with the high value or low value from the table in Figure 5 associated with the active mode, and (iii) if the said symbol character is a shift character, changing to a specified new current decoding mode; and
  - (c) generating a signal uniquely representing the scanned codeword.
- 50
- 65

21. A method for decoding signals produced by scanning a data file structure that includes a plurality of

codewords organized into at least two adjacent rows, each codeword being a representation of at least one human-recognizable symbol and each codeword in any one row being distinct from any codeword in an adjacent row, said method including the steps of:

- 5 (a) determining whether a scanned codeword lies in one said row or in another adjacent row;
  - (b) computing a unique index number for a codeword as a function of a detectable characteristic of the codeword; and
  - (c) processing the index number to generate a signal representative of the said at least one human-recognizable symbol.
- 10 22. A method as set forth in claim 21 in which the step of determining whether a scanned codeword lies in one said row or in another adjacent row includes the step of computing a discriminator function of a detectable characteristic of the codeword.
- 15 23. A method as set forth in claim 21 in which the step of determining whether a scanned codeword lies in one said row or in another adjacent row includes the step of computing a function  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  of the codeword, where each  $x_i$  for a codeword represents the width of an  $i^{\text{th}}$  mark of the codeword.
- 20 24. A method as set forth in claim 21 in which the step of determining whether a scanned codeword lies in one said row or in another adjacent row includes the steps of:
- (a) computing a function  $f(X) = (x_1 - x_3 + x_5 - x_7) \bmod 9$  of the codeword; and
  - (b) computing a function  $t_k = x_k + x_{k+1}$  for  $k = 1, \dots, 7$ ,
  - (c) where each  $x_i$  for a codeword represents the width of an  $i^{\text{th}}$  mark of the codeword.
- 25 25. A method as set forth in claim 21 in which the step of processing the index number includes the step of determining whether the codeword includes a representation of a mode-switching symbol.
26. Apparatus comprising means for performing the method steps of any one of claims 14 through 25.
- 30 27. A storage device tangibly embodying a program of instructions that are readable by a machine and that, when executed by the machine, result in the performance by the machine of the method steps of any one of claims 14 through 25.
- 35 28. A method for storing and retrieving information by scanning indicia on the surface of a substrate, said indicia including a plurality of codewords scan sequentially and organized into at least two adjacent rows, each codeword being either an information codeword or a control codeword, each information codeword being a representation of at least one information-containing data structure, a plurality of different protocols each associating the code word with a corresponding data structure, only one protocol being active at any given time, each codeword in any one row being distinct from any
- 40 codeword in an adjacent row, said method comprising the steps of:
- (a) determining whether a scanned codeword is an information codeword or a control codeword;
  - (b) decoding said codeword according to the active protocol if said codeword is an information codeword;
  - (c) processing said codeword if said codeword is a control codeword to derive a pointer to a new protocol, and changing the active protocol to the new protocol; and
  - 45 (d) repeating steps (a) through (c) until all codewords are decoded.

50

55

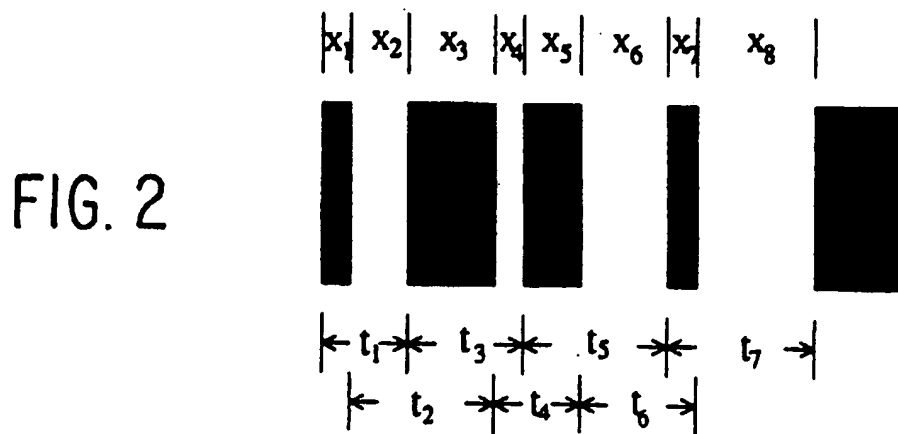
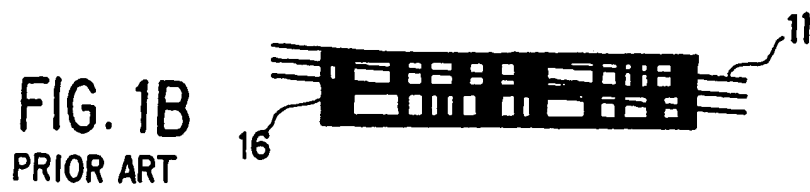
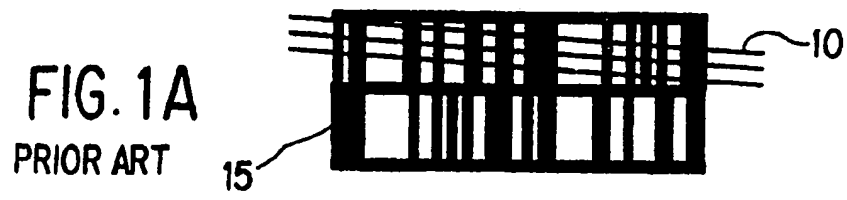




FIG. 3

row0	Cluster0
row1	Cluster3
row2	Cluster6
row4	Cluster0
row n	Cluster $(n \bmod 3) * 3$

FIG. 4



Value/Mode	Alpha	Mixed	Numeric	User(s)			
0	A	0	0	user defined value			
1	B	1					
2	C	2					
3	D	3					
4	E	4					
5	F	5					
6	G	6					
7	H	7					
8	I	8					
9	J	9					
10	K	A	to	mode 3   mode 20 to   to mode 19   mode 29			
11	L	B					
12	M	C					
13	N	D					
14	O	E					
15	P	F					
16	Q	!					
17	R	\$					
18	S	%					
19	T	&					
20	U	*					
21	V	(					
22	W	)					
23	X	-					
24	Y	+					
25	Z	=					
26	-	/					
27	space	:					
28	ms	as					
29	us	us					
30							
to							
925							
926							
927							
928							
			925 space as ms	as ms			

FIG. 5



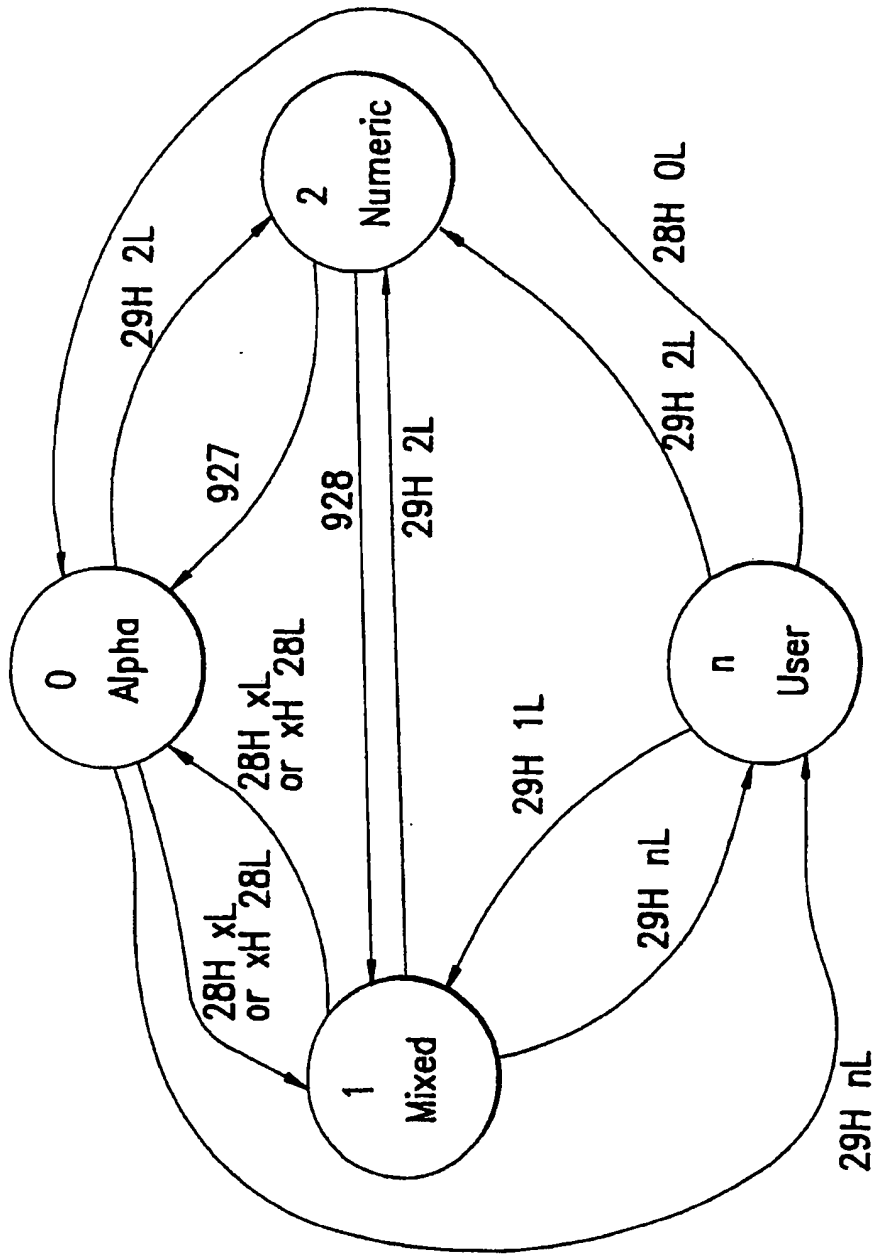
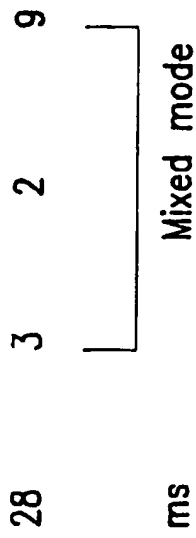


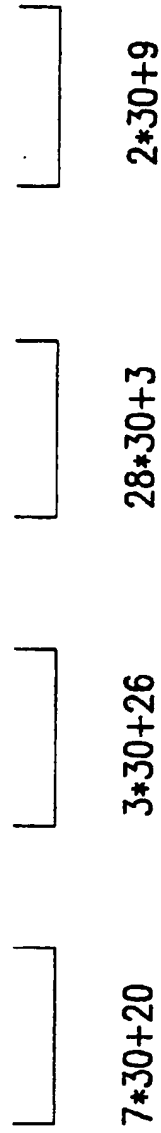
FIG. 6

original  
text

H U D - 3 2 9



encoding of  
each pair  
into base-30  
digits



codeword  
to use

230	116	843	69
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FIG. 7

FIG. 8

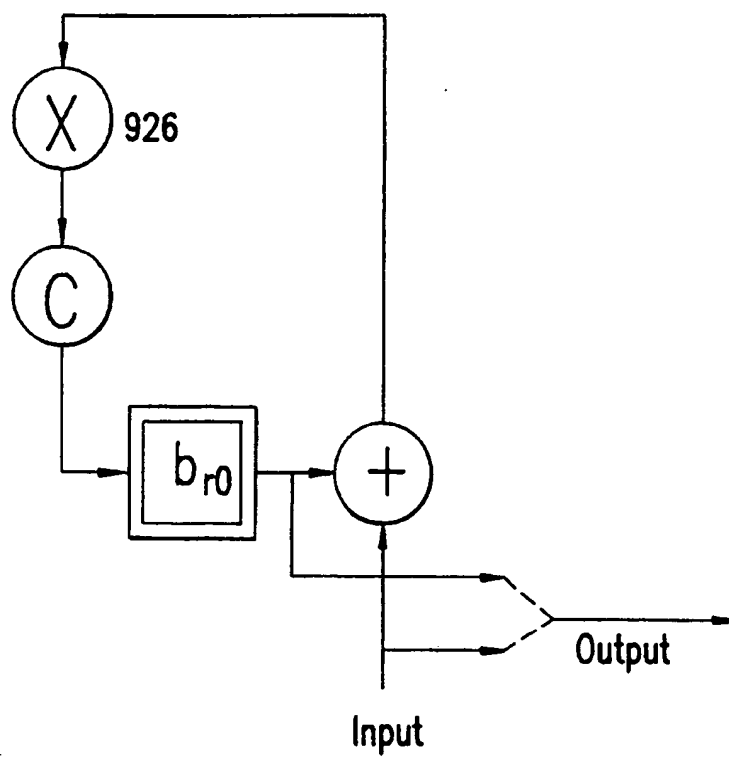
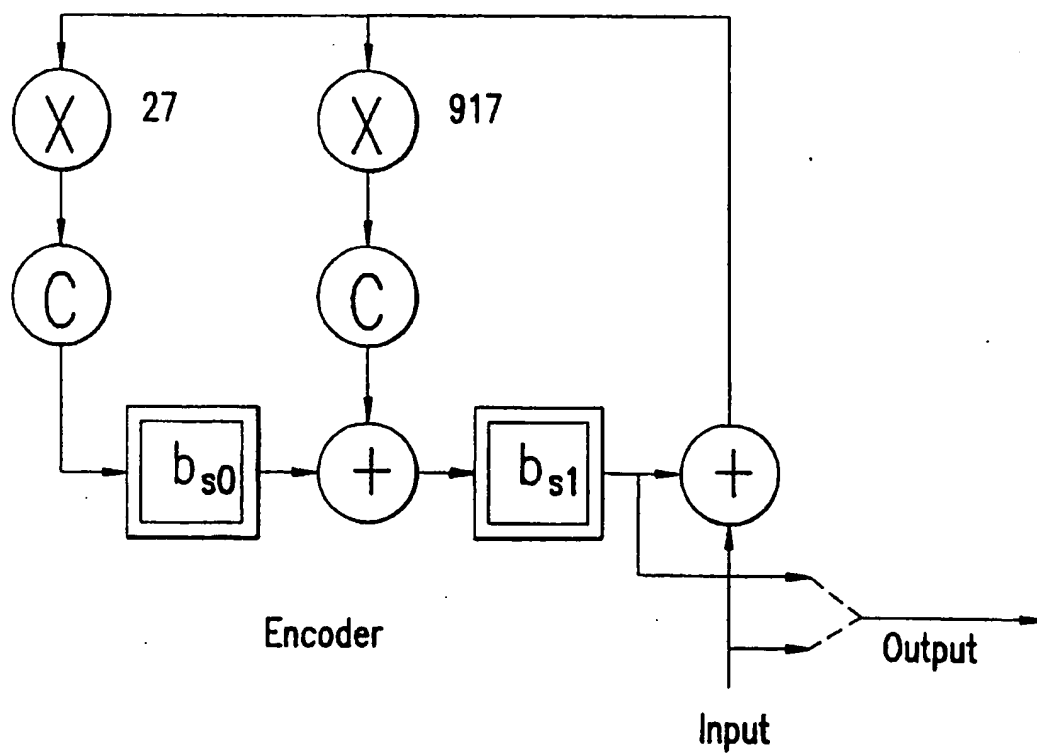


FIG. 9



$a_{1,n-1}$	$a_{1,n-2}$		$a_{1,1}$	$a_{1,0}$	$b_{1,r0}$
$a_{2,n-1}$	$a_{2,n-2}$		$a_{2,1}$	$a_{2,0}$	$b_{2,r0}$
$a_{m-1,n-1}$	$a_{m-1,n-2}$		$a_{m-1,1}$	$a_{m-1,0}$	$b_{m-1,r0}$
$a_{m,n-1}$	$a_{m,n-2}$		$b_{s1}$	$b_{s0}$	$b_{m,r0}$

FIG. 10

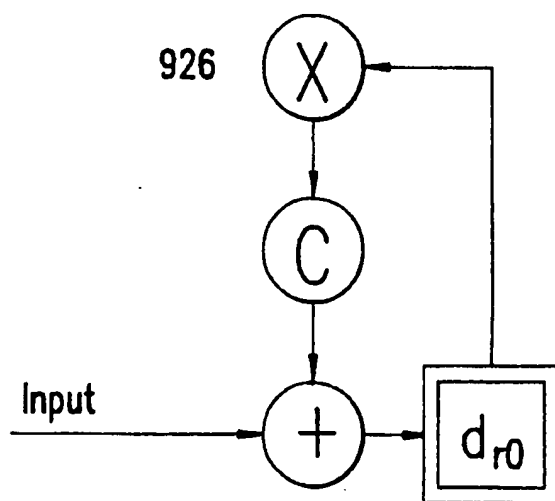


FIG. 11

Syndrome divider

FIG. 12

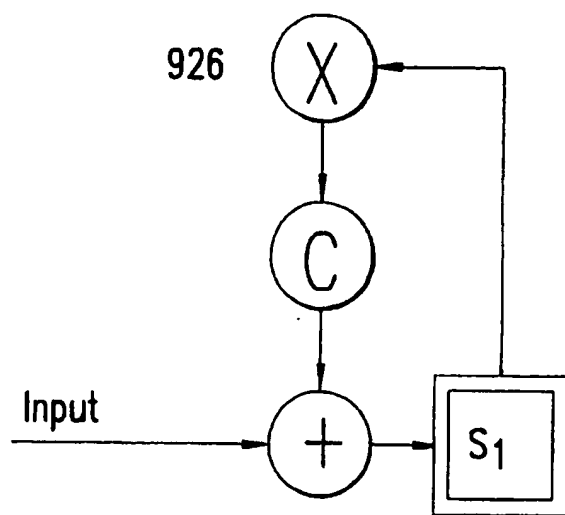


FIG. 13

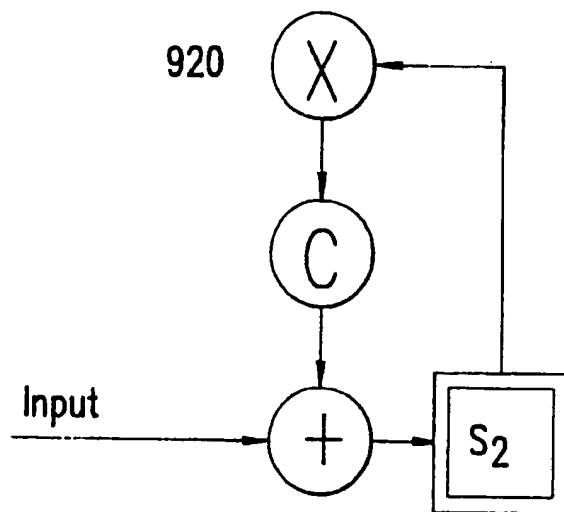


Table I : The t-sequence table. Cluster0							
t-seq	val	t-seq	val	t-seq	val	t-seq	val
222266	0	226655	50	244664	100	324545	150
222277	1	226666	51	245542	101	324556	151
222355	2	226733	52	245553	102	324645	152
222366	3	226755	53	245564	103	324656	153
222444	4	227722	54	245653	104	325523	154
222455	5	227744	55	245664	105	325534	155
222466	6	227766	56	245764	106	325545	156
222477	7	233354	57	246642	107	325556	157
222555	8	233365	58	246653	108	325567	158
222566	9	233443	59	246664	109	325634	159
222666	10	233454	60	246675	110	325645	160
222677	11	233465	61	246764	111	325656	161
223355	12	233476	62	247753	112	325745	162
223366	13	233554	63	255552	113	326623	163
223444	14	233565	64	255563	114	326634	164
223455	15	233665	65	255574	115	326645	165
223466	16	233676	66	255663	116	326656	166
223544	17	234443	67	256652	117	326745	167
223555	18	234454	68	256663	118	327734	168
223566	19	234465	69	256674	119	332255	169
223577	20	234476	70	257752	120	332266	170
223655	21	234543	71	266662	121	332344	171
223666	22	234554	72	267762	122	332355	172
223677	23	234565	73	322245	123	332366	173
224444	24	234654	74	322256	124	332444	174
224455	25	234665	75	322267	125	332455	175
224466	26	234765	76	322334	126	332466	176
224533	27	235532	77	322345	127	332477	177
224544	28	235543	78	322356	128	332555	178
224555	29	235554	79	322445	129	332566	179
224566	30	235565	80	322456	130	332577	180
224577	31	235643	81	322467	131	332666	181
224644	32	235654	82	322556	132	333244	182
224655	33	235665	83	323334	133	333255	183
224666	34	235676	84	323345	134	333266	184
224755	35	235765	85	323356	135	333333	185
225533	36	236632	86	323434	136	333344	186
225544	37	236643	87	323445	137	333355	187
225555	38	236654	88	323456	138	333366	188
225566	39	236665	89	323467	139	333377	189
225577	40	236743	90	323545	140	333433	190
225633	41	236765	91	323556	141	333444	191
225644	42	237732	92	323567	142	333455	192
225655	43	237754	93	323656	143	333466	193
225666	44	244442	94	324423	144	333477	194
225744	45	244453	95	324434	145	333544	195
225766	46	244464	96	324445	146	333555	196
226622	47	244553	97	324456	147	333566	197
226633	48	244564	98	324467	148	333655	198
226644	49	244575	99	324534	149	333666	199

FIG. 14A

Table I : The t-sequence table. Cluster0					
t-seq	val	t-seq	val	t-seq	val
343343	250	354453	300	424546	350
343354	251	354464	301	425524	351
343365	252	354475	302	425535	352
343376	253	354553	303	425546	353
343443	254	354564	304	425635	354
343454	255	354575	305	426624	355
343465	256	354664	306	426635	356
343554	257	355442	307	432234	357
343565	258	355453	308	432245	358
343665	259	355464	309	432256	359
344332	260	355542	310	432334	360
344343	261	355553	311	432345	361
344354	262	355564	312	432356	362
344365	263	355653	313	432367	363
344432	264	355664	314	432445	364
344443	265	356542	315	432456	365
344454	266	356553	316	432467	366
344465	267	356564	317	432556	367
344543	268	356642	318	433223	368
344554	269	356653	319	433234	369
344565	270	356664	320	433245	370
344576	271	356753	321	433256	371
344654	272	357653	322	433267	372
344665	273	357753	323	433323	373
345432	274	365552	324	433334	374
345443	275	365563	325	433345	375
345454	276	365563	326	433356	376
345465	277	366552	327	433367	377
345532	278	366563	328	433434	378
345543	279	366652	329	433445	379
345554	280	366663	330	433456	380
345565	281	367752	331	433545	381
345576	282	422224	332	433556	382
345643	283	422235	333	434323	383
345654	284	422246	334	434334	384
345665	285	422335	335	434345	385
345754	286	422346	336	434356	386
346532	287	422357	337	434367	387
346543	288	422446	338	434423	388
346554	289	423324	339	434434	389
346565	290	423335	340	434445	390
346632	291	423346	341	434456	391
346643	292	423435	342	434534	392
346654	293	423446	343	434545	393
346665	294	423546	344	434556	394
346754	295	424424	345	434645	395
347643	296	424435	346	435423	396
347732	297	424446	347	435434	397
347754	298	424457	348	435445	398
354442	299	424535	349	435456	399
				442555	400
				442566	401
				442577	402
				442588	403
				442599	404
				442610	405
				442621	406
				442632	407
				442643	408
				442654	409
				442665	410
				442676	411
				442687	412
				442698	413
				442709	414
				442720	415
				442731	416
				442742	417
				442753	418
				442764	419
				442775	420
				442786	421
				442797	422
				442808	423
				442819	424
				442830	425
				442841	426
				442852	427
				442863	428
				442874	429
				442885	430
				442896	431
				442907	432
				442918	433
				442929	434
				442940	435
				442951	436
				442962	437
				442973	438
				442984	439
				442995	440
				443006	441
				443017	442
				443028	443
				443039	444
				443050	445
				443061	446
				443072	447
				443083	448
				443094	449

FIG. 14B

Table I : The t-sequence table. Cluster0									
t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val
446733	500	456643	550	533335	600	544445	650	554222	700
447522	501	456654	551	533346	601	544456	651	554233	701
447544	502	456743	552	533435	602	544534	652	554244	702
447633	503	457543	553	533446	603	544545	653	554255	703
447722	504	457643	554	534324	604	545323	654	554266	704
447744	505	457743	555	534335	605	545334	655	554322	705
453332	506	464442	556	534346	606	545345	656	554333	706
453343	507	464453	557	534424	607	545423	657	554344	707
453354	508	464464	558	534435	608	545434	658	554355	708
453365	509	464553	559	534446	609	545445	659	554366	709
453443	510	464564	560	534535	610	545523	660	554422	710
453454	511	465442	561	535424	611	545534	661	554433	711
453465	512	465453	562	535435	612	545545	662	554444	712
453476	513	465464	563	535524	613	545634	663	554455	713
453554	514	465542	564	535535	614	546423	664	554466	714
453565	515	465553	565	536524	615	546434	665	554533	715
454332	516	465564	566	536624	616	546523	666	554544	716
454343	517	465653	567	542223	617	546534	667	554555	717
454354	518	466442	568	542234	618	546623	668	554644	718
454365	519	466453	569	542245	619	546634	669	555222	719
454432	520	466542	570	542256	620	547623	670	555233	720
454443	521	466553	571	542334	621	552233	671	555244	721
454454	522	466642	572	542345	622	552244	672	555255	722
454465	523	466653	573	542356	623	552255	673	555322	723
454476	524	467642	574	542367	624	552266	674	555333	724
454543	525	475552	575	542445	625	552277	675	555344	725
454554	526	476552	576	542456	626	552333	676	555355	726
454565	527	522225	577	543223	627	552344	677	555422	727
454654	528	522236	578	543234	628	552355	678	555433	728
455332	529	522247	579	543245	629	552366	679	555444	729
455343	530	522336	580	543256	630	552444	680	555455	730
455354	531	523325	581	543323	631	552455	681	555522	731
455365	532	523336	582	543334	632	552466	682	555533	732
455432	533	523347	583	543345	633	552555	683	555544	733
455443	534	523436	584	543356	634	553222	684	555555	734
455454	535	524425	585	543367	635	553233	685	555633	735
455465	536	524436	586	543434	636	553244	686	555644	736
455532	537	525525	587	543445	637	553255	687	556322	737
455543	538	532224	588	543456	638	553266	688	556333	738
455554	539	532235	589	543545	639	553322	689	556344	739
455565	540	532246	590	544223	640	553333	690	556422	740
455643	541	532257	591	544234	641	553344	691	556433	741
455654	542	532335	592	544245	642	553355	692	556444	742
456432	543	532346	593	544256	643	553366	693	556522	743
456443	544	532357	594	544323	644	553433	694	556533	744
456454	545	532446	595	544334	645	553444	695	556544	745
456532	546	533224	596	544345	646	553455	696	556622	746
456543	547	533235	597	544356	647	553466	697	556633	747
456554	548	533246	598	544423	648	553544	698	556644	748
456632	549	533324	599	544434	649	553555	699	557422	749

FIG. 14C



Table I : The t-sequence table. Cluster0					
t-seq	val	t-seq	val	t-seq	val
557522	750	632225	800	654223	850
557622	751	632236	801	654234	851
555722	752	632247	802	654245	852
563332	753	632336	803	654323	853
563343	754	633225	804	654334	854
563354	755	633236	805	654345	855
563365	756	633325	806	654423	856
563443	757	633336	807	654434	857
563454	758	634325	808	654445	858
563465	759	634425	809	654534	859
563554	760	642224	810	655223	860
564332	761	642235	811	655234	861
564343	762	642246	812	655323	862
564354	763	642335	813	655334	863
564365	764	642346	814	655423	864
564432	765	643224	815	655434	865
564443	766	643235	816	655523	866
564454	767	643246	817	655534	867
564465	768	643324	818	656323	868
564543	769	643335	819	656423	869
564554	770	643346	820	656523	870
565332	771	643435	821	656623	871
565343	772	644224	822	662222	872
565354	773	644235	823	662233	873
565432	774	644324	824	662244	874
565443	775	644335	825	662255	875
565454	776	644424	826	662266	876
565532	777	644435	827	662277	877
565543	778	645324	828	662333	878
565554	779	645424	829	662344	879
565643	780	645524	830	662355	880
566332	781	652223	831	662366	881
566343	782	652234	832	662444	882
566432	783	652245	833	662455	883
566443	784	652256	834	663222	884
566532	785	652267	835	663233	885
566543	786	652334	836	663244	886
566632	787	652345	837	663255	887
566643	788	652356	838	663266	888
567432	789	652445	839	663322	889
567632	790	653223	840	663333	890
574442	791	653234	841	663344	891
574464	792	653245	842	663355	892
575442	793	653256	843	663366	893
575542	794	653323	844	663433	894
576442	795	653334	845	663444	895
576642	796	653345	846	663455	896
622226	797	653356	847	663544	897
622772	798	653434	848	664222	898
623326	799	653445	849	664233	899

FIG. 14 D

Table I : The t-sequence table. Cluster3					
t-seq val	t-seq val	t-seq val	t-seq val	t-seq val	t-seq val
222563	0	234327	50	266224	100
222574	1	234338	51	266235	101
222585	2	234349	52	266246	102
222596	3	234762	53	266257	103
222663	4	234773	54	266335	104
222674	5	234784	55	266346	105
222685	6	234795	56	267324	106
222696	7	234873	57	267335	107
222774	8	234884	58	267346	108
222785	9	235427	59	267435	109
222796	10	235438	60	268424	110
223652	11	235862	61	268435	111
223663	12	235873	62	269524	112
223674	13	235884	63	277223	113
223685	14	235973	64	277234	114
223696	15	236527	65	277245	115
223763	16	236962	66	277256	116
223774	17	236973	67	277334	117
223785	18	244226	68	277345	118
223796	19	244237	69	278323	119
223874	20	244248	70	278334	120
223885	21	244259	71	278345	121
224752	22	244337	72	278434	122
224763	23	244348	73	279423	123
224774	24	244772	74	279434	124
224785	25	244783	75	322453	125
224796	26	244794	76	322464	126
224863	27	245326	77	322475	127
224874	28	245337	78	322486	128
224885	29	245348	79	322497	129
224974	30	245437	80	322553	130
225852	31	245872	81	322564	131
225863	32	245883	82	322575	132
225874	33	246426	83	322586	133
225885	34	246437	84	322597	134
225963	35	246972	85	322664	135
225974	36	247526	86	322675	136
226952	37	255225	87	322686	137
226963	38	255236	88	322775	138
226974	39	255247	89	323542	139
233227	40	255258	90	323553	140
233238	41	255336	91	323564	141
233249	42	255347	92	323575	142
233662	43	256325	93	323586	143
233673	44	256336	94	323597	144
233684	45	256347	95	323653	145
233695	46	256436	96	323664	146
233773	47	257425	97	323675	147
233784	48	257436	98	323686	148
233795	49	258525	99	323764	149
				323775	150
				324642	151
				324653	152
				324664	153
				324675	154
				324686	155
				324753	156
				324764	157
				324775	158
				324864	159
				325742	160
				325753	161
				325764	162
				325775	163
				325853	164
				325864	165
				326842	166
				326853	167
				326864	168
				326953	169
				327942	170
				327953	171
				332552	172
				332563	173
				332574	174
				332585	175
				332596	176
				332663	177
				332674	178
				332685	179
				332696	180
				332774	181
				332785	182
				333552	183
				333563	184
				333574	185
				333585	186
				333596	187
				333652	188
				333663	189
				333674	190
				333685	191
				333696	192
				333763	193
				333774	194
				333785	195
				333874	196
				334652	197
				334663	198
				334674	199
				334685	200
				334752	201
				334763	202
				334774	203
				334785	204
				334863	205
				334874	206
				335752	207
				335763	208
				335774	209
				335852	210
				335863	211
				335874	212
				335963	213
				336852	214
				336863	215
				336952	216
				336963	217
				337952	218
				343227	219
				343238	220
				343249	221
				343662	222
				343673	223
				343684	224
				343695	225
				343773	226
				343784	227
				344227	228
				344238	229
				344327	230
				344338	231
				344662	232
				344673	233
				344684	234
				344762	235
				344773	236
				344784	237
				344873	238
				345327	239
				345427	240
				345762	241
				345773	242
				345862	243
				345873	244
				346862	245
				346962	246
				354226	247
				354237	248
				354248	249

FIG. 15A

Table I : The t-sequence table. Cluster3									
t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val
354337	250	422576	300	433475	350	443685	400	497223	450
354772	251	422665	301	433486	351	443763	401	497234	451
354783	252	423432	302	433542	352	443774	402	498323	452
355226	253	423443	303	433553	353	444552	403	522233	453
355237	254	423454	304	433564	354	444563	404	522244	454
355326	255	423465	305	433575	355	444574	405	522255	455
355337	256	423476	306	433586	356	444652	406	522266	456
355772	257	423487	307	433653	357	444663	407	522277	457
355872	258	423543	308	433664	358	444674	408	522333	458
356326	259	423554	309	433675	359	444752	409	522344	459
356426	260	423565	310	433764	360	444763	410	522355	460
365225	261	423576	311	434542	361	444774	411	522366	461
365236	262	423654	312	434553	362	444863	412	522377	462
365247	263	423665	313	434564	363	445652	413	522444	463
365336	264	424532	314	434575	364	445663	414	522455	464
366225	265	424543	315	434642	365	445752	415	522466	465
366236	266	424554	316	434653	366	445763	416	522555	466
366325	267	424565	317	434664	367	445852	417	523322	467
366336	268	424576	318	434675	368	445863	418	523333	468
367325	269	424643	319	434753	369	446752	419	523344	469
367425	270	424654	320	434764	370	446852	420	523355	470
376224	271	424665	321	435642	371	446952	421	523366	471
376235	272	424754	322	435653	372	453227	422	523377	472
376246	273	425632	323	435664	373	453238	423	523433	473
376335	274	425643	324	435742	374	453662	424	523444	474
377224	275	425654	325	435753	375	453673	425	523455	475
377235	276	425665	326	435764	376	453684	426	523466	476
377324	277	425743	327	435853	377	453773	427	523544	477
377335	278	425754	328	436742	378	454227	428	523555	478
378324	279	426732	329	436753	379	454327	429	524422	479
378424	280	426743	330	436842	380	454662	430	524433	480
387223	281	426754	331	436853	381	454673	431	524444	481
387234	282	426843	332	437842	382	454762	432	524455	482
387245	283	427832	333	437942	383	454773	433	524466	483
387334	284	427843	334	442552	384	455662	434	524533	484
388323	285	432442	335	442563	385	455762	435	524544	485
388334	286	432453	336	442574	386	455862	436	524555	486
389423	287	432464	337	442585	387	464226	437	524644	487
422343	288	432475	338	442596	388	464237	438	525522	488
422354	289	432486	339	442663	389	464772	439	525533	489
422365	290	432497	340	442674	390	465226	440	525544	490
422376	291	432553	341	442685	391	465326	441	525555	491
422387	292	432564	342	442774	392	475225	442	525633	492
422443	293	432575	343	443552	393	475236	443	525644	493
422454	294	432586	344	443563	394	476225	444	526622	494
422465	295	432664	345	443574	395	476325	445	526633	495
422476	296	432675	346	443585	396	486224	446	526644	496
422487	297	433442	347	443652	397	486235	447	526733	497
422554	298	433453	348	443663	398	487224	448	527722	498
422565	299	433464	349	443674	399	487324	449	527733	499

FIG. 15B

Table I : The t-sequence table. Cluster3					
t-seq	val	t-seq	val	t-seq	val
532332	500	542453	550	554552	600
532343	501	542464	551	554563	601
532354	502	542475	552	554572	602
532365	503	542486	553	554583	603
532376	504	542497	554	554594	604
532387	505	542508	555	554605	605
532443	506	542519	556	554616	606
532454	507	542530	557	554627	607
532465	508	542541	558	554638	608
532476	509	542552	559	554649	609
532554	510	542563	560	554660	610
532565	511	542574	561	554671	611
533332	512	542585	562	554682	612
533343	513	542596	563	554693	613
533354	514	542607	564	554704	614
533365	515	542618	565	554715	615
533376	516	542629	566	554726	616
533432	517	542640	567	554737	617
533443	518	542651	568	554748	618
533454	519	542662	569	554759	619
533465	520	542673	570	554770	620
533476	521	542684	571	554781	621
533543	522	542695	572	554792	622
533554	523	542706	573	554803	623
533565	524	542717	574	554814	624
533654	525	542728	575	554825	625
534432	526	542739	576	554836	626
534443	527	542750	577	554847	627
534454	528	542761	578	554858	628
534465	529	542772	579	554869	629
534532	530	542783	580	554880	630
534543	531	542794	581	554891	631
534554	532	542805	582	554902	632
534565	533	542816	583	554913	633
534643	534	542827	584	554924	634
534654	535	542838	585	554935	635
535532	536	542849	586	554946	636
535543	537	542860	587	554957	637
535554	538	542871	588	554968	638
535632	539	542882	589	554979	639
535643	540	542893	590	554990	640
535654	541	542904	591	555001	641
535743	542	542915	592	555012	642
536632	543	542926	593	555023	643
536643	544	542937	594	555034	644
536732	545	542948	595	555045	645
536743	546	542959	596	555056	646
537732	547	542970	597	555067	647
537832	548	542981	598	555078	648
542442	549	542992	599	555089	649
632444	650	643354	700		
632455	651	643365	701		
633222	652	643432	702		
633233	653	643443	703		
633244	654	643454	704		
633255	655	643465	705		
633266	656	643543	706		
633322	657	643554	707		
633333	658	644332	708		
633344	659	644343	709		
633355	660	644354	710		
633366	661	644432	711		
633433	662	644443	712		
633444	663	644454	713		
633455	664	644532	714		
633544	665	644543	715		
634322	666	644554	716		
634333	667	644643	717		
634344	668	645432	718		
634355	669	645443	719		
634422	670	645532	720		
634433	671	645543	721		
634444	672	645632	722		
634455	673	645643	723		
634533	674	646532	724		
634544	675	646632	725		
635422	676	646732	726		
635433	677	652442	727		
635444	678	652453	728		
635522	679	652464	729		
635533	680	652475	730		
635544	681	652553	731		
635633	682	652564	732		
636522	683	653442	733		
636533	684	653453	734		
636622	685	653464	735		
636633	686	653542	736		
637622	687	653553	737		
637722	688	653564	738		
642332	689	653653	739		
642343	690	654442	740		
642354	691	654453	741		
642365	692	654542	742		
642376	693	654553	743		
642443	694	654642	744		
642454	695	654653	745		
642465	696	655442	746		
642554	697	655542	747		
643332	698	655642	748		
643343	699	655742	749		

FIG. 15C

Table I : The t-sequence table. Cluster3					
t-seq	val	t-seq	val	t-seq	val
662552	750	743255	800	762453	850
662563	751	743322	801	762464	851
662574	752	743333	802	762553	852
662663	753	743344	803	763442	853
663552	754	743355	804	763453	854
663563	755	743433	805	763542	855
663652	756	743444	806	763553	856
663663	757	744222	807	764442	857
664552	758	744233	808	764542	858
664652	759	744244	809	764642	859
664752	760	744322	810	772552	860
673662	761	744333	811	772563	861
722224	762	744344	812	773552	862
722235	763	744422	813	773652	863
722246	764	744433	814	832224	864
722335	765	744444	815	832235	865
723324	766	744533	816	833324	866
723335	767	745322	817	842223	867
724424	768	745333	818	842234	868
732223	769	745422	819	842245	869
732234	770	745433	820	842334	870
732245	771	745522	821	843223	871
732256	772	745533	822	843234	872
732334	773	746422	823	843323	873
732345	774	746522	824	843334	874
733223	775	746622	825	844323	875
733234	776	752332	826	844423	876
733245	777	752343	827	852222	877
733323	778	752354	828	852233	878
733334	779	752365	829	852244	879
733345	780	752443	830	852255	880
733434	781	752454	831	852333	881
734323	782	753332	832	852344	882
734334	783	753343	833	853222	883
734423	784	753354	834	853233	884
734434	785	753432	835	853244	885
735423	786	753443	836	853322	886
735523	787	753454	837	853333	887
742222	788	753543	838	853344	888
742233	789	754332	839	853433	889
742244	790	754343	840	854222	890
742255	791	754432	841	854233	891
742266	792	754443	842	854322	892
742333	793	754532	843	854333	893
742344	794	754543	844	854422	894
742355	795	755332	845	854433	895
742444	796	755432	846	855322	896
743222	797	755532	847	855422	897
743233	798	755632	848	855522	898
743244	799	762442	849	862332	899

FIG. 15D

Table I : The t-sequence table. Cluster6											
t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val
222236	0	233357	50	244445	100	255555	150	268643	200		
222247	1	233368	51	244456	101	256322	151	269632	201		
222258	2	233379	52	244467	102	256333	152	269643	202		
222269	3	233446	53	244556	103	256344	153	277442	203		
222336	4	233457	54	245323	104	256355	154	277453	204		
222347	5	233468	55	245334	105	256366	155	277464	205		
222358	6	233557	56	245345	106	256377	156	277553	206		
222369	7	234324	57	245356	107	256433	157	278542	207		
222447	8	234335	58	245367	108	256444	158	278553	208		
222458	9	234346	59	245378	109	256455	159	279642	209		
222469	10	234357	60	245434	110	256466	160	322226	210		
223325	11	234368	61	245445	111	256544	161	322237	211		
223336	12	234379	62	245456	112	256555	162	322248	212		
223347	13	234435	63	245467	113	257422	163	322259	213		
223358	14	234446	64	245545	114	257433	164	322337	214		
223369	15	234457	65	245556	115	257444	165	322348	215		
223436	16	234468	66	246423	116	257455	166	322359	216		
223447	17	234546	67	246434	117	257466	167	322772	217		
223458	18	234557	68	246445	118	257533	168	322783	218		
223469	19	235424	69	246456	119	257544	169	322794	219		
223547	20	235435	70	246467	120	257555	170	323326	220		
223558	21	235446	71	246534	121	257644	171	323337	221		
224425	22	235457	72	246545	122	258522	172	323348	222		
224436	23	235468	73	246556	123	258533	173	323359	223		
224447	24	235535	74	246645	124	258544	174	323437	224		
224458	25	235546	75	247523	125	258555	175	323448	225		
224469	26	235557	76	247534	126	258633	176	323872	226		
224536	27	235646	77	247545	127	258644	177	323883	227		
224547	28	236524	78	247556	128	259622	178	323894	228		
224558	29	236535	79	247634	129	259633	179	324426	229		
224647	30	236546	80	247645	130	259644	180	324437	230		
225525	31	236557	81	248623	131	259733	181	324448	231		
225536	32	236635	82	248634	132	266332	182	324537	232		
225547	33	236646	83	248645	133	266343	183	324972	233		
225558	34	237624	84	248734	134	266354	184	324983	234		
225636	35	237635	85	249723	135	266365	185	325526	235		
225647	36	237646	86	249734	136	266376	186	325537	236		
226625	37	237735	87	255233	137	266443	187	326626	237		
226636	38	238724	88	255244	138	266454	188	332225	238		
226647	39	238735	89	255255	139	266465	189	332236	239		
226736	40	244234	90	255266	140	266554	190	332247	240		
227725	41	244245	91	255277	141	267432	191	332258	241		
227736	42	244256	92	255333	142	267443	192	332269	242		
233235	43	244267	93	255344	143	267454	193	332336	243		
233246	44	244278	94	255355	144	267465	194	332347	244		
233257	45	244334	95	255366	145	267543	195	332358	245		
233268	46	244345	96	255377	146	267554	196	332369	246		
233279	47	244356	97	255444	147	268532	197	332447	247		
233335	48	244367	98	255455	148	268543	198	332458	248		
233346	49	244378	99	255466	149	268554	199	333225	249		

FIG. 16A

Table I : The t-sequence table. Cluster6											
t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val
333236	250	344246	300	355256	350	366266	400	387442	450		
333247	251	344257	301	355267	351	366322	401	387453	451		
333258	252	344268	302	355323	352	366333	402	388542	452		
333269	253	344324	303	355334	353	366344	403	422227	453		
333325	254	344335	304	355345	354	366355	404	422238	454		
333336	255	344346	305	355356	355	366366	405	422249	455		
333347	256	344357	306	355367	356	366433	406	422662	456		
333358	257	344368	307	355434	357	366444	407	422673	457		
333369	258	344435	308	355445	358	366455	408	422684	458		
333436	259	344446	309	355456	359	366544	409	422695	459		
333447	260	344457	310	355545	360	367322	410	422773	460		
333458	261	344546	311	356323	361	367333	411	422784	461		
333547	262	345324	312	356334	362	367344	412	423327	462		
334325	263	345335	313	356345	363	367355	413	423338	463		
334336	264	345346	314	356356	364	367422	414	423762	464		
334347	265	345357	315	356423	365	367433	415	423773	465		
334358	266	345424	316	356434	366	367444	416	423784	466		
334425	267	345435	317	356445	367	367455	417	423873	467		
334436	268	345446	318	356456	368	367533	418	424427	468		
334447	269	345457	319	356534	369	367544	419	424862	469		
334458	270	345535	320	356545	370	368422	420	424873	470		
334536	271	345546	321	357423	371	368433	421	425962	471		
334547	272	346424	322	357434	372	368444	422	432226	472		
335425	273	346435	323	357445	373	368522	423	432237	473		
335436	274	346446	324	357523	374	368533	424	432248	474		
335447	275	346524	325	357534	375	368544	425	432259	475		
335525	276	346535	326	357545	376	368633	426	432337	476		
335536	277	346546	327	357634	377	369522	427	432348	477		
335547	278	346635	328	358523	378	369533	428	432772	478		
335636	279	347524	329	358534	379	369622	429	432783	479		
336525	280	347535	330	358623	380	369633	430	432794	480		
336536	281	347624	331	358634	381	376332	431	433226	481		
336625	282	347635	332	359623	382	376343	432	433237	482		
336636	283	348624	333	359723	383	376354	433	433248	483		
337625	284	348724	334	365222	384	376365	434	433326	484		
337725	285	354223	335	365233	385	376443	435	433337	485		
343224	286	354234	336	365244	386	376454	436	433348	486		
343235	287	354245	337	365255	387	377332	437	433437	487		
343246	288	354256	338	365266	388	377343	438	433772	488		
343257	289	354267	339	365277	389	377354	439	433783	489		
343268	290	354278	340	365333	390	377432	440	433872	490		
343279	291	354334	341	365344	391	377443	441	433883	491		
343335	292	354345	342	365355	392	377454	442	434326	492		
343346	293	354356	343	365366	393	377543	443	434337	493		
343357	294	354367	344	365444	394	378432	444	434426	494		
343368	295	354445	345	365455	395	378443	445	434437	495		
343446	296	354456	346	366222	396	378532	446	434872	496		
343457	297	355223	347	366233	397	378543	447	434972	497		
344224	298	355234	348	366244	398	379532	448	435426	498		
344235	299	355245	349	366255	399	379632	449	435526	499		

FIG. 16B

Table I : The t-sequence table. Cluster6					
t-seq	val	t-seq	val	t-seq	val
442225	500	454257	550	466345	600
442236	501	454324	551	466423	601
442247	502	454335	552	466434	602
442268	503	454346	553	466445	603
442269	504	454357	554	466534	604
442336	505	454435	555	467323	605
442347	506	454446	556	467334	606
442358	507	455224	557	467423	607
442447	508	455235	558	467434	608
443225	509	455246	559	467523	609
443236	510	455324	560	467534	610
443247	511	455335	561	468423	611
443258	512	455346	562	468523	612
443325	513	455424	563	468623	613
443336	514	455435	564	475222	614
443347	515	455446	565	475233	615
443358	516	455535	566	475244	616
443436	517	456324	567	475255	617
443447	518	456335	568	475266	618
444225	519	456424	569	475333	619
444236	520	456435	570	475344	620
444247	521	456524	571	475355	621
444325	522	456535	572	475444	622
444336	523	457424	573	476222	623
444347	524	457524	574	476233	624
444425	525	457624	575	476244	625
444436	526	464223	576	476255	626
444447	527	464234	577	476322	627
444536	528	464245	578	476333	628
445325	529	464256	579	476344	629
445336	530	464267	580	476355	630
445425	531	464334	581	476433	631
445436	532	464345	582	476444	632
445525	533	464356	583	477222	633
445536	534	464445	584	477233	634
446425	535	465223	585	477244	635
446525	536	465234	586	477322	636
446625	537	465245	587	477333	637
453224	538	465256	588	477344	638
453235	539	465323	589	477422	639
453246	540	465334	590	477433	640
453257	541	465345	591	477444	641
453268	542	465356	592	477533	642
453335	543	465434	593	478322	643
453346	544	465445	594	478333	644
453357	545	466223	595	478422	645
453446	546	466234	596	478433	646
454224	547	466245	597	478522	647
454235	548	466323	598	478533	648
454246	549	466334	599	479422	649
				479522	650
				479622	651
				486332	652
				486343	653
				486354	654
				486443	655
				487332	656
				487343	657
				487432	658
				487443	659
				488432	660
				488532	661
				497442	662
				522552	663
				522563	664
				522574	665
				522585	666
				522663	667
				522674	668
				523652	669
				523663	670
				523674	671
				523763	672
				524752	673
				524763	674
				525852	675
				532227	676
				532238	677
				532662	678
				532673	679
				532684	680
				532773	681
				533227	682
				533327	683
				533662	684
				533673	685
				533762	686
				533773	687
				534762	688
				534862	689
				542226	690
				542237	691
				542248	692
				542337	693
				542772	694
				542783	695
				543226	696
				543237	697
				543326	698
				543337	699
				543772	700
				543872	701
				544226	702
				544326	703
				544426	704
				552225	705
				552236	706
				552247	707
				552258	708
				552336	709
				552347	710
				553225	711
				553236	712
				553247	713
				553325	714
				553336	715
				553347	716
				553436	717
				554225	718
				554236	719
				554325	720
				554336	721
				554425	722
				554436	723
				555225	724
				555325	725
				555425	726
				555525	727
				563224	728
				563235	729
				563246	730
				563257	731
				563335	732
				563346	733
				564224	734
				564235	735
				564246	736
				564324	737
				564335	738
				564346	739
				564435	740
				565224	741
				565235	742
				565324	743
				565335	744
				565424	745
				565435	746
				566224	747
				566324	748
				566424	749

FIG. 16C



Table I : The t-sequence table. Cluster6

t-seq	val	t-seq	val	t-seq	val	t-seq	val	t-seq	val
566524	750	622442	800	674324	850	742552	900		
574223	751	622453	801	674335	851	742563	901		
574234	752	622464	802	675224	852	743552	902		
574245	753	622475	803	675324	853	743652	903		
574256	754	622553	804	675424	854	752662	904		
574334	755	622564	805	684223	855	762226	905		
574345	756	623542	806	684234	856	772225	906		
575223	757	623553	807	684245	857	772236	907		
575234	758	623564	808	684334	858	773225	908		
575245	759	623653	809	685223	859	773325	909		
575323	760	624642	810	685234	860	783224	910		
575334	761	624653	811	685323	861	783235	911		
575345	762	625742	812	685334	862	784224	912		
575434	763	632552	813	686223	863	784324	913		
576223	764	632563	814	686323	864	794223	914		
576234	765	632574	815	686423	865	794234	915		
576323	766	632663	816	695222	866	795223	916		
576334	767	633552	817	695233	867	795323	917		
576423	768	633563	818	695244	868	832332	918		
576434	769	633652	819	695333	869	832343	919		
577223	770	633663	820	696222	870	832354	920		
577323	771	634652	821	696233	871	832443	921		
577423	772	634752	822	696322	872	833432	922		
577523	773	642227	823	696333	873	833443	923		
585222	774	642662	824	697222	874	834532	924		
585233	775	642673	825	697322	875	842442	925		
585244	776	643662	826	697422	876	842453	926		
585255	777	643762	827	722332	877	843442	927		
585333	778	652226	828	722343	878	843542	928		
585344	779	652237	829	722354	879				
586222	780	652772	830	722365	880				
586233	781	653226	831	722443	881				
586244	782	653326	832	722454	882				
586322	783	662225	833	723432	883				
586333	784	662236	834	723443	884				
586344	785	662247	835	723454	885				
586433	786	662336	836	723543	886				
587222	787	663225	837	724532	887				
587233	788	663236	838	724543	888				
587322	789	663325	839	725632	889				
587333	790	663336	840	732442	890				
587422	791	664225	841	732453	891				
587433	792	664325	842	732464	892				
588322	793	664425	843	732553	893				
588422	794	673224	844	733442	894				
588522	795	673235	845	733453	895				
596332	796	673246	846	733542	896				
596343	797	673335	847	733553	897				
597332	798	674224	848	734542	898				
597432	799	674235	849	734642	899				

FIG. 16D

## FIG. 17A

../src/pdf174.c

```
#include <stdio.h>
#define MODULE 9

FILE *fopen(), *fout[9];

int t[8];
int x[8] = {0,0,0,0,0,0,0,0};
int b[13] = {0,0,0,0,0,0,0,0,0,0,0,0,0};
int m = 7;
int n = 9; /*17 - 8*/
int other = 0;
int total = 0;

int grteq(i)
int i;
{
    int k, flag;

    flag=0;
    for(k=0;k<=m;k++) if(x[k] >= i) flag=1;
    return(flag);
}
```

## FIG. 17B

```

void s(i)
int i;
{
int k,sum,j,tmp;

sum=0;
for(k=0;k<i;k++) sum += x[k];
if(i == m){
x[m] = n - sum;
for(k=0;k<m;k++) t[k] = x[k]+x[k+1];
tmp = x[0] - x[2] + x[4] - x[6];
tmp = tmp%MODULE;
if(tmp < 0) tmp += MODULE;
total++;
if(grteq(6)) other++;
else( b[tmp]++;
for(k=0;k<m;k++)
fprintf(fout[tmp],"%d ",t[k]+2);
fprintf(fout[tmp],"\\n");
}
}
else(
for(j=0;j<=(n-sum);j++){x[i]=j; s(i+1);}
}
}

```

## FIG. 17C

```
main()
{
  int k;

  fout[0]=fopen("out0","w");
  fout[1]=fopen("out1","w");
  fout[2]=fopen("out2","w");
  fout[3]=fopen("out3","w");
  fout[4]=fopen("out4","w");
  fout[5]=fopen("out5","w");
  fout[6]=fopen("out6","w");
  fout[7]=fopen("out7","w");
  fout[8]=fopen("out8","w");
  s(0);
  for(k=0;k<MODULE;k++) fclose(fout[k]);
}
```

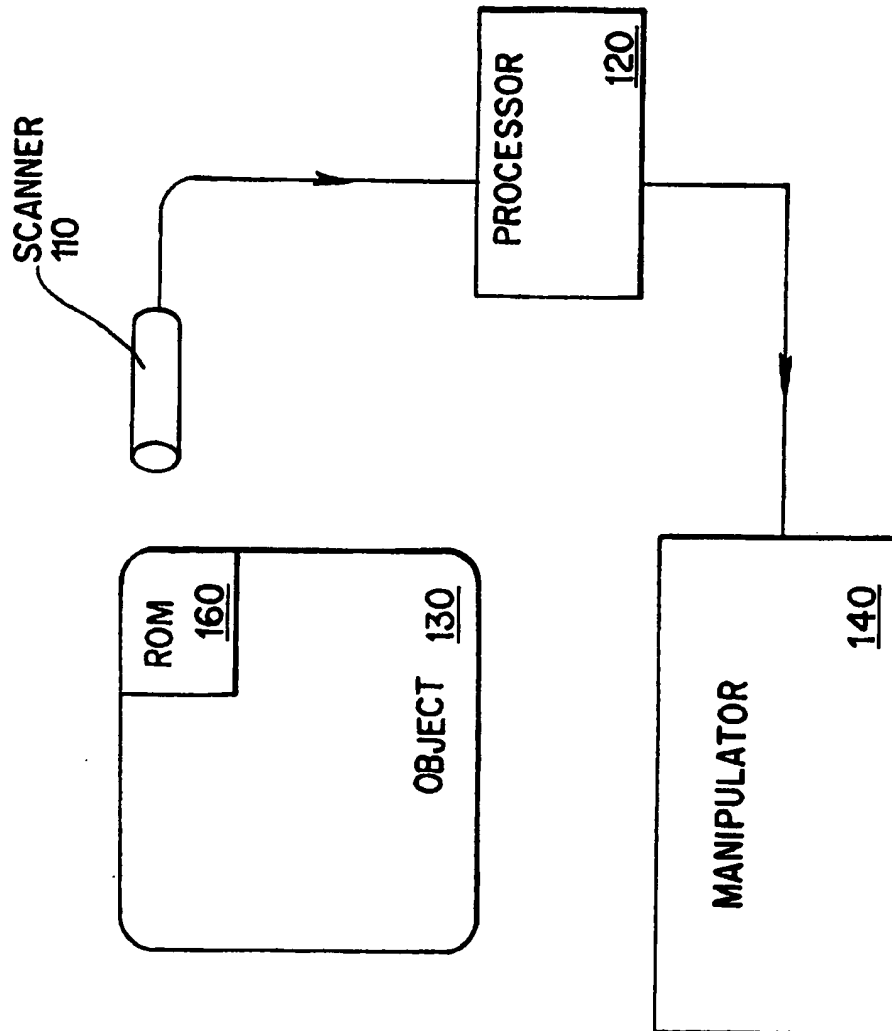


FIG. 18

FIG. 19a

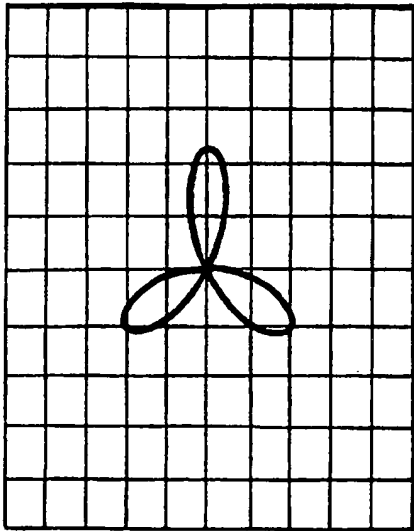


FIG. 19b

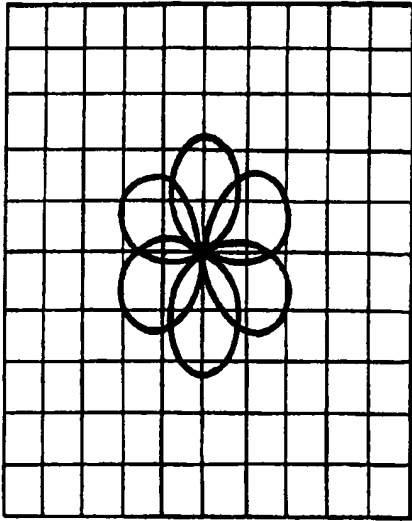


FIG. 19c

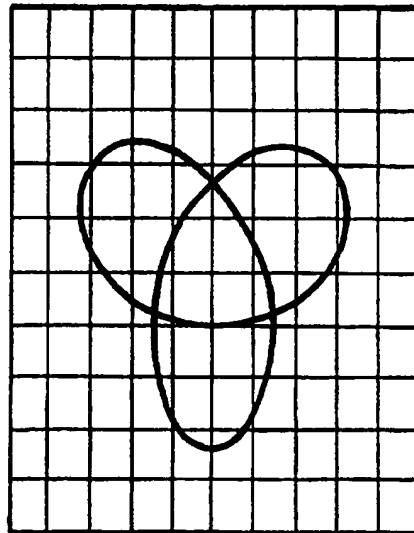
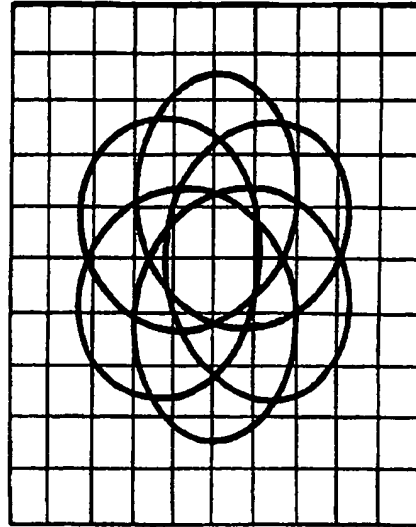


FIG. 19d



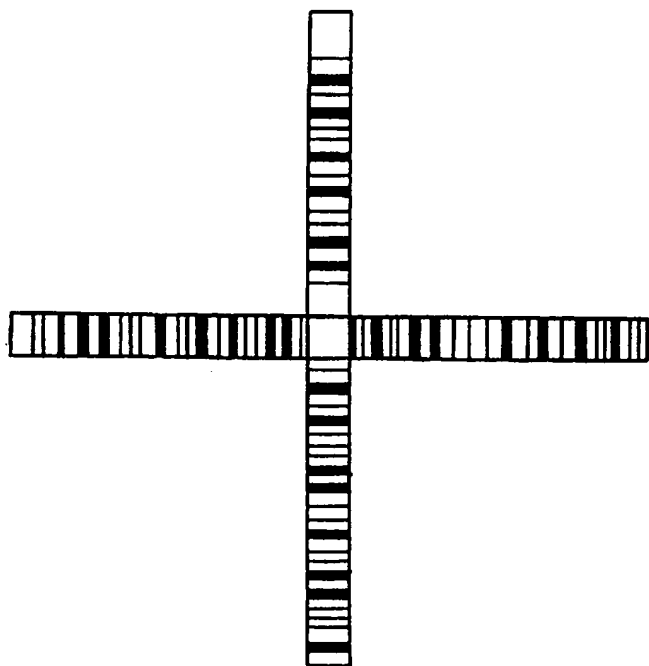


FIG. 20

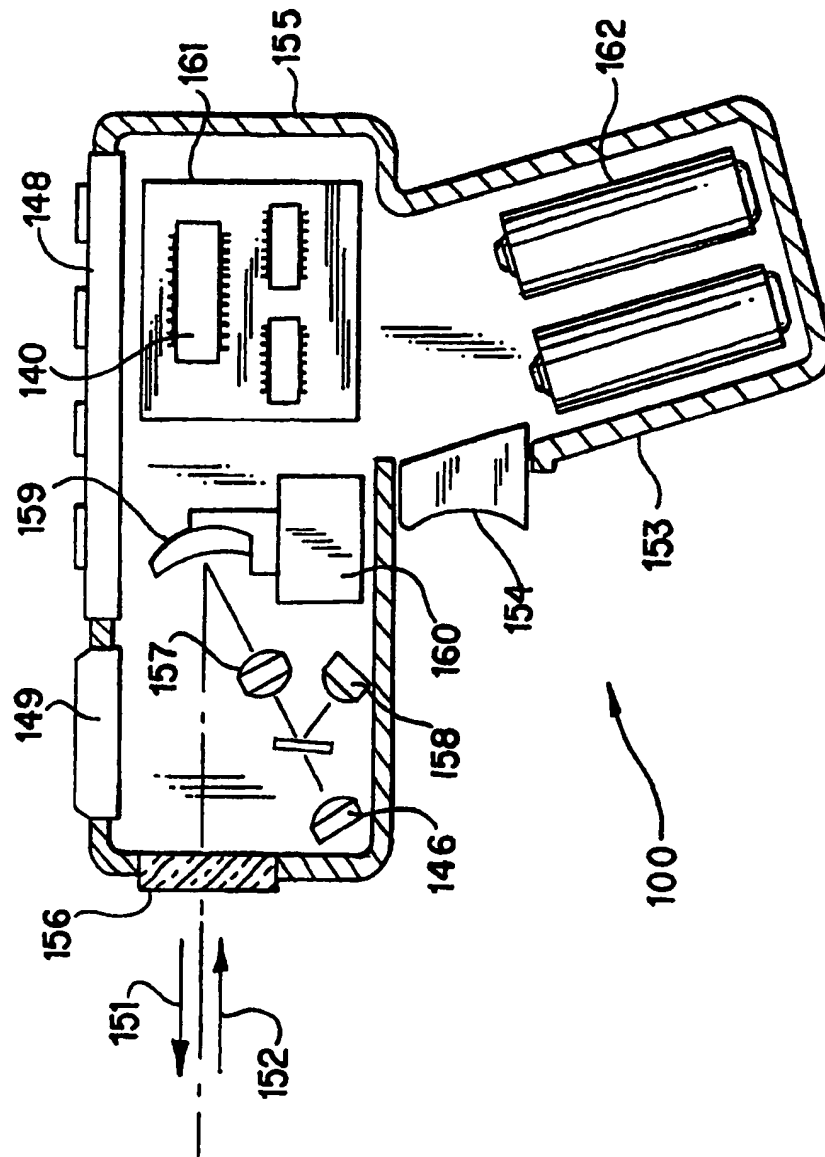


FIG. 21